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# Revision Rates after Primary Hip and Knee Replacement in England between 2003 and 2006

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**Abbreviations:** CI, confidence interval; HES, Hospital Episode Statistics; NHS, National Health Service; NJR, National Joint Registry

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## ABSTRACT

### Background

Hip and knee replacement are some of the most frequently performed surgical procedures in the world. Resurfacing of the hip and unicondylar knee replacement are increasingly being used. There is relatively little evidence on their performance. To study performance of joint replacement in England, we investigated revision rates in the first 3 y after hip or knee replacement according to prosthesis type.

### Methods and Findings

We linked records of the National Joint Registry for England and Wales and the Hospital Episode Statistics for patients with a primary hip or knee replacement in the National Health Service in England between April 2003 and September 2006. Hospital Episode Statistics records of succeeding admissions were used to identify revisions for any reason. 76,576 patients with a primary hip replacement and 80,697 with a primary knee replacement were included (51% of all primary hip and knee replacements done in the English National Health Service). In hip patients, 3-y revision rates were 0.9% (95% confidence interval [CI] 0.8%–1.1%) with cemented, 2.0% (1.7%–2.3%) with cementless, 1.5% (1.1%–2.0% CI) with “hybrid” prostheses, and 2.6% (2.1%–3.1%) with hip resurfacing ( $p < 0.0001$ ). Revision rates after hip resurfacing were increased especially in women. In knee patients, 3-y revision rates were 1.4% (1.2%–1.5% CI) with cemented, 1.5% (1.1%–2.1% CI) with cementless, and 2.8% (1.8%–4.5% CI) with unicondylar prostheses ( $p < 0.0001$ ). Revision rates after knee replacement strongly decreased with age.

### Interpretation

Overall, about one in 75 patients needed a revision of their prosthesis within 3 y. On the basis of our data, consideration should be given to using hip resurfacing only in male patients and unicondylar knee replacement only in elderly patients.

*The Editors' Summary of this article follows the references.*

## Introduction

Total hip replacement was first successfully performed in 1962 in the United Kingdom and approved for use in the United States in 1969 [1,2]. Total knee replacement was introduced in its modern form in the early 1970s [3]. Since then, these procedures have developed at an astonishing pace and they are now among the most frequently performed major surgical procedures in the world. In 2006, about 160,000 total hip and knee replacement procedures were carried out in England and Wales and about 500,000 in the United States [4,5].

A large number of different designs of hip and knee prostheses have been developed and introduced on the market. For example in England and Wales in 2006, at least 155 different brands of acetabular cups and 176 different brands of femoral stems were used for hip replacement and 86 different prosthesis brands for knee replacement [4]. It can be expected that these numbers will continue to increase both as a result of new suppliers entering the market and new brands being introduced by existing suppliers. These prosthesis brands are most often grouped according to the method of fixation of the components into cemented and cementless prostheses. Other types are metal-on-metal resurfacing of the hip and unicondylar knee replacement.

Metal-on-metal resurfacing of the hip has been developed as an alternative procedure that conserves femoral bone and only replaces the surface of the joint [6]. Resurfacing in its modern form was introduced in the mid-1990s as an alternative solution especially for physically active patients [7]. In this procedure, the femur is “resurfaced” with a hemispherical metal component and the femoral head and neck are not removed. The acetabulum is replaced just as in a total hip replacement. It is advocated that a revision of a modern resurfacing procedure is less problematic in terms of blood loss, operation time, and functional results than a revision of a cemented or cementless prosthesis, which is an advantage in young patients who are likely to outlive the lifespan of their hip prosthesis. However, resurfacing is the topic of much debate and some argue that its benefits have only been demonstrated in specialist centres and in selected groups of patients [8].

The unicondylar knee replacement was originally introduced in the mid-1980s as a procedure for patients with joint damage that is limited to either the medial or lateral compartment of the knee [9]. In this procedure, only the damaged knee compartment is replaced. They are increasingly being used as a result of both continuing improvements in its design and the gradual development of minimally invasive surgery. The indications for unicondylar prostheses remain to be defined. Some studies show higher revision rates for this type of prosthesis than for total knee replacement, whereas others show rates that are similar [10,11].

There is relatively little high-quality evidence on the performance of the different prosthesis types available for hip and knee replacement and even less on the performance of individual brands. In a number of countries, national registries were established to fill this gap and to identify poorly performing prostheses as early as possible after their introduction on the market [12–18]. These national registries demonstrate that overall revision rates after primary hip and knee replacements are declining, which demonstrates the

remarkable success of a rather unsystematic process of innovation lacking formal evaluation.

The National Joint Registry (NJR) for England and Wales was established in April 2003 to provide patients, healthcare professionals, regulators, and suppliers with timely evidence on the performance of prosthesis brands [19,20]. It collects information that is available immediately after surgery on the characteristics of the patients including the indication for surgery, the prostheses that are implanted, and the surgical procedures used.

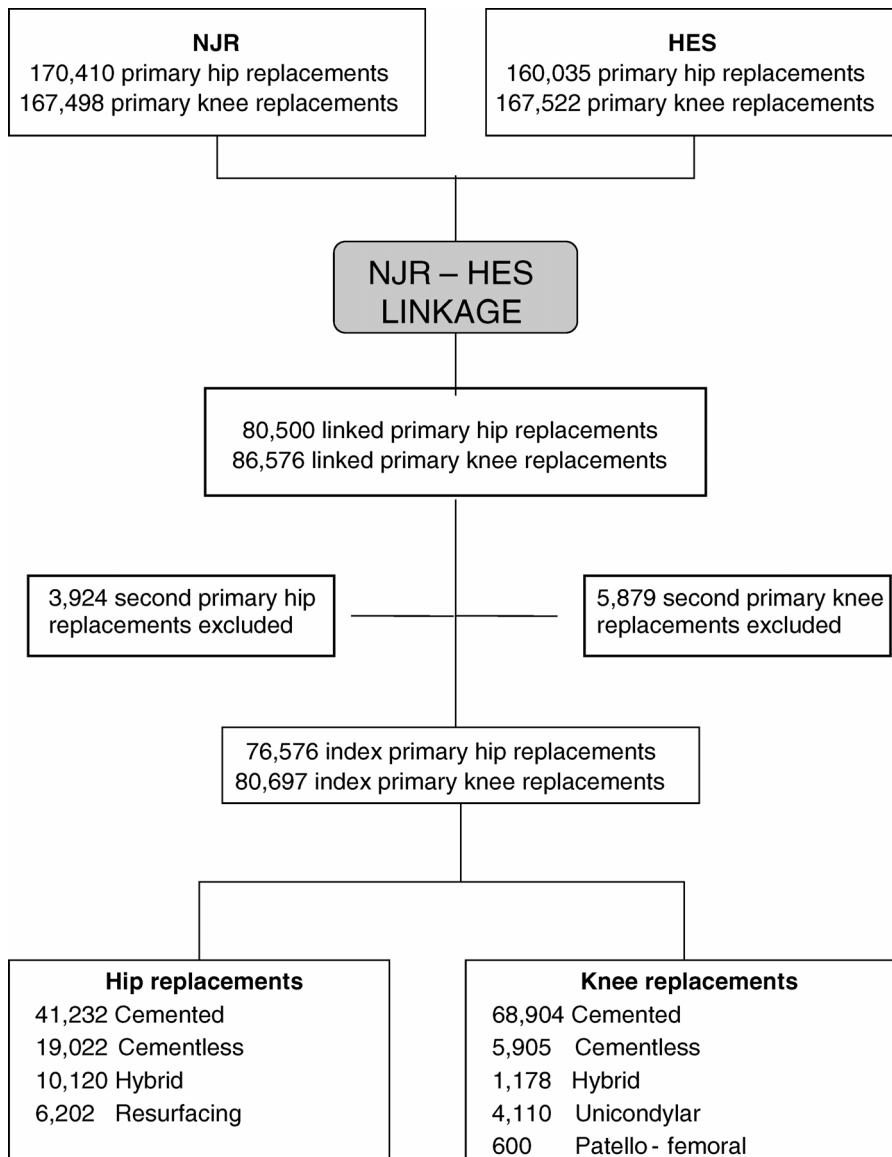
The NJR covers a population that is considerably larger than any of the existing national joint registries (53.7 million in 2006), which puts it in a unique position to provide information on large numbers of patients who have recently undergone a joint replacement. The emphasis on replacements that took place in recent years is important because of the observed decline in revision rates. The NJR can furthermore achieve near complete follow-up through linkage with the Hospital Episode Statistics database (HES) that contains records of all admissions to National Health Service (NHS) hospitals in England [21]. Through the linkage of NJR and HES records, we were able to benefit from the detailed clinical information available in the NJR and the completeness of follow-up through HES.

We considered revision rates for any reason in the first 3 y after primary hip and knee replacement as a measure of performance. We investigated how these rates differed according to prosthesis type and we gave special attention to revision rates after hip resurfacing and unicondylar knee replacement.

## Methods

The NJR aims to collect data on all hip and knee replacements in England and Wales. Candidates for inclusion are patients who undergo a cemented, cementless, or “hybrid” total hip replacement or hip resurfacing, those who undergo a total knee replacement, unicondylar replacement, or patello-femoral replacement, and those who had a revision of any of these procedures. Hybrid hip prostheses have one cemented and one cementless component. Further information can be found in the NJR 4th Annual Report [4]. We considered all 170,410 NJR records on primary hip procedures and 167,498 on primary knee procedures carried out between April 1, 2003 and September 30, 2006 (Figure 1).

A revision for any reason was used as outcome. Revisions were identified through linkage with the HES database. We did not use the NJR database to identify revisions, because incomplete case ascertainment and missing patient identifiers in the NJR would have led to considerable underestimation. The HES database contains routinely collected records on admissions of patients treated in England in NHS hospitals, in NHS treatment centres, as well as of those treated in independent hospitals and independent sector treatment centres with NHS funding [21]. The HES database also contains date of death through linkage with the mortality records of the Office for National Statistics. Procedures are coded according to the Office of Population, Censuses and Surveys Classification of Surgical Operations and Procedures, 4th Revision (OPCS-4) [22]. Admissions for primary hip replacements were identified in HES if the first procedure field contained the codes W371 (primary total prosthetic



**Figure 1.** Linkage of NJR with the HES Database  
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replacement of hip joint using cement), W381 (primary total prosthetic replacement of hip joint not using cement), W391 (primary total prosthetic replacement of hip joint not elsewhere classified), and W581 (primary resurfacing arthroplasty of joint) in combination with Z843 (hip joint).

Admissions for primary knee replacement were identified if the first procedure field contained the codes W401 (primary total prosthetic replacement of knee joint using cement), W411 (primary total prosthetic replacement of knee joint not using cement), W421 (primary total prosthetic replacement of knee joint not elsewhere classified), W581 (primary resurfacing arthroplasty) in combination with Z846 (knee joint), and W521 (primary prosthetic replacement of articulation of bone using cement not elsewhere classified). The HES database contained 160,035 records of primary hip procedures and 167,522 primary knee procedures (Figure 1).

Linkage of NJR records and HES records was carried out according to five hierarchical linkage criteria: (1) local

hospital number and NHS Trust code; (2) NHS number and NHS Trust code; (3) NHS number only; (4) patient date of birth, sex, and NHS Trust code; and (5) patient date of birth and NHS Trust code. Linkage was considered to be successful if both the NJR and the HES record described a primary hip replacement or a primary knee replacement and if the date of the joint replacement according to the NJR was within the start and end dates of the episode (i.e., the period that an admitted patient is under the care of a consultant) according to HES. A number of patients had undergone bilateral primary hip or primary knee procedures on different dates. In such cases, only the earliest primary procedure was retained in the linked database to avoid including the same patient twice.

For each patient with a linked primary procedure, all hospital admissions recorded in HES succeeding the primary procedure were identified on the basis of a unique patient identifier available in HES (HESID), which is based on the

**Table 1.** Characteristics of Patients Who Had a Primary Hip Replacement

Category	Characteristic	Prosthesis Type									
		Total Hip Replacement Using Cement		Total Hip Replacement Not Using Cement		Hybrid Total Hip Replacement		Hip Resurfacing		Overall	
		n	Percent	n	Percent	n	Percent	n	Percent	n	Percent
Age	<55 y	1,634	4	2,937	15	1,313	13	3,098	50	8,982	12
	55–64 y	5,998	15	6,020	32	2,733	27	2,551	41	17,302	23
	65–74 y	16,642	40	6,727	35	3,776	37	516	8	27,661	36
	75+ y	16,957	41	3,338	18	2,298	23	37	<1	22,630	29
	Not recorded	1	—	0	—	0	—	0	—	1	—
Sex	Female	26,512	64	10,840	57	5,969	59	2,359	38	45,680	60
	Male	14,705	36	8,172	43	4,148	41	3,843	62	30,868	40
	Not recorded	15	—	10	—	3	—	0	—	28	—
Indication for surgery	Osteoarthritis	38,854	94	17,701	93	9,274	92	5,879	95	71,708	94
	Other	2,378	6	1,321	7	846	8	323	5	4,868	6
<b>Total</b>		41,232	—	19,022	—	10,120	—	6,202	—	76,576	—

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patients' sex, date of birth, and NHS number or in case NHS number was unavailable on sex, date of birth, postcode, and local hospital number. From these succeeding admissions, the first revision that occurred on the same side as the primary was selected. Where the side of the primary or the revision was not recorded, the first revision that occurred after the primary procedure was assumed to be a revision of that primary procedure.

Hip revision procedures were identified using the OPCS-4 procedure codes W373 (revision of total prosthetic replacement of hip joint using cement), W383 (revision of total prosthetic replacement of hip joint not using cement), W393 (revision of total prosthetic replacement of hip joint not elsewhere classified), W372 (conversion to total prosthetic replacement of hip joint using cement), W382 (conversion to total prosthetic replacement of hip joint not using cement), W392 (conversion to total prosthetic replacement of hip joint not elsewhere classified), W394 (attention to total prosthetic replacement of hip joint not elsewhere classified) in combination with Y032 (renewal of prosthesis in organ not otherwise classified), and W582 (revision of resurfacing arthroplasty of joint) in combination with Z843 (hip joint) [23,24].

Knee revision procedures were identified using the codes W403 (revision of total prosthetic replacement of knee joint using cement), W413 (revision of total prosthetic replacement of knee joint not using cement), W423 (revision of total prosthetic replacement of knee joint not elsewhere classified), W402 (conversion to total prosthetic replacement of knee joint using cement), W412 (conversion to total prosthetic replacement of knee joint not using cement), W422 (conversion to total prosthetic replacement of knee joint not elsewhere classified), W424 (attention to total prosthetic replacement of knee joint) in combination with Y032 (renewal of prosthesis in organ not otherwise classified), and W582 (revision of resurfacing arthroplasty of joint) in combination with Z846 (knee joint) [23,24].

Using the revisions identified in HES as described above, revision rates were then estimated for the different prosthesis types. Revision rates were estimated using the Kaplan-Meier survival analysis method with time of death or September 30,

2006 as the end of follow-up. The nonparametric Peto-Peto-Prentice test, a modification of the log-rank test that gives greater weight to observations made early in the course of follow-up, was used to test whether revision rates over time were equal among the different prosthesis types.

Multivariable Cox regression was used to estimate hazard ratios for prosthesis type, age group, sex, and indication for surgery as risk factors for revision [25]. In all models, age was included as a categorical variable. Hazard ratios can be considered as relative risks related to each risk factor with adjustment for the other factors. The partial likelihood ratio test was used to test whether risk factors had an effect on the revision rates by comparing one by one the log likelihood of models that did and did not contain these risk factors. The partial likelihood ratio test was used in a similar way to test for interaction by comparing models that did and did not contain the interaction terms.

The proportional hazard assumption was assessed by testing the interaction of log time from operation with prosthesis type. We found *p*-values of 0.1 for hip prosthesis type and 0.8 for knee prosthesis type, which indicates that we can accept that the hazard functions of the different prosthesis types are proportional for both hips and knees. Stata software (version 9.2) was used in all analyses.

## Results

Of the 327,557 primary hip or knee replacement procedures carried out between April 1, 2003 and September 30, 2006 in the NHS in England according to the HES database, 167,076 (51%) could be linked to an NJR record (Figure 1). The remaining records could not be linked because the NJR records did not contain the necessary patient identifiers. After removal of 9,803 records of the second joint replacement in patients who had undergone bilateral primary hip or knee replacements on different dates, 157,273 patients were available for analysis (Tables 1 and 2).

### Revision Rates after Hip Replacement

76,576 patients in the linked database had undergone a primary hip replacement. Of these patients, 41,232 (54%) had

**Table 2.** Characteristics of Patients Who Had a Primary Knee Replacement

Category	Characteristic	Prosthesis Type											
		Total Knee Replacement Using Cement		Total Knee Replacement Not Using Cement		Hybrid Total Knee Replacement		Unicondylar Knee Replacement		Patello-Femoral Replacement		Overall	
		n	Percent	n	Percent	n	Percent	n	Percent	n	Percent	n	Percent
Age	<55 y	3,158	5	345	6	79	7	507	12	145	24	4,234	5
	55–64 y	13,905	20	1,338	23	255	22	1,329	32	169	28	16,996	21
	65–74 y	21,111	39	2,335	39	461	39	1,446	35	171	29	31,524	39
	75+ y	24,728	36	1,887	32	383	32	828	20	115	19	27,941	35
	Not recorded	—	—	—	—	—	—	—	—	—	—	—	—
Sex	Female	40,163	58	3,247	55	668	57	2,067	50	446	74	46,591	58
	Male	28,715	42	2,657	45	510	43	2,043	50	154	26	34,079	42
	Not recorded	15	—	10	—	3	—	0	—	28	—	—	—
Indication for surgery	Osteoarthritis	66,252	96	5,715	97	1,123	95	4,066	99	578	96	77,734	96
	Other	2,652	4	190	3	55	5	44	1	22	4	2,963	4
<b>Total</b>		68,904	—	5,905	—	1,178	—	4,110	—	600	—	80,697	—

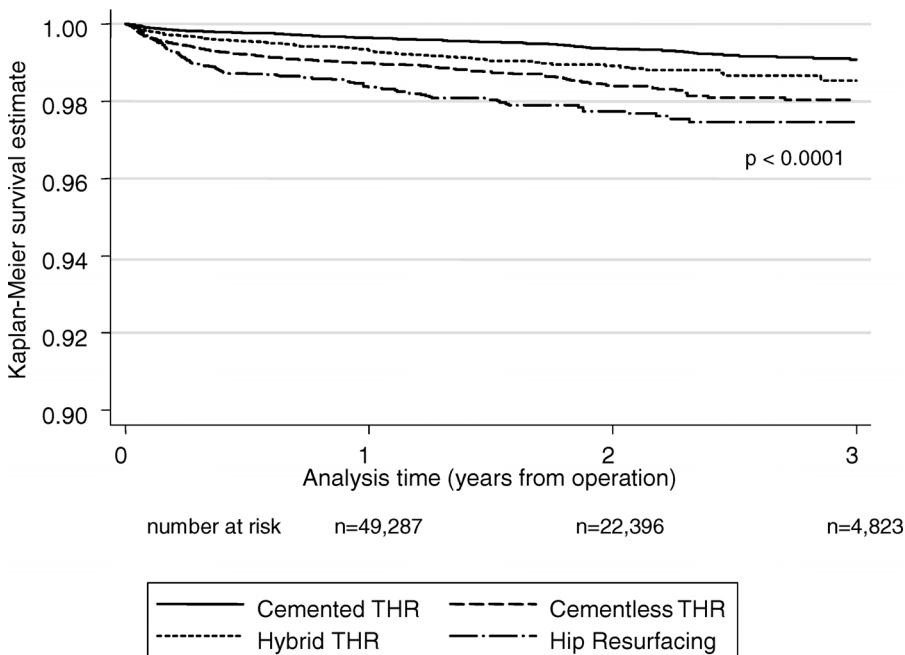
doi:10.1371/journal.pmed.0050179.t002

received a cemented prosthesis, 19,022 (25%) had received a cementless prosthesis, 10,120 (13%) had received a hybrid prosthesis, and 6,202 (8%) had undergone resurfacing (Table 1). The age and sex of the patients and type of prosthesis used were strongly associated. For example, 91% of the patients who underwent resurfacing were younger than 65 y and about two-thirds were men, whereas 81% of those who received a cemented prosthesis were 65 y or older and about two-thirds were women. Overall, 94% of patients who underwent a hip replacement because of osteoarthritis and this percentage was similar across the prosthesis groups.

The overall revision rate following primary hip replace-

ment was 0.7% (95% confidence interval [CI] 0.6%–0.7%) at 1 y and 1.4% (95% CI 1.2%–1.5%) at 3 y. Revision rates varied according to the type of prosthesis used ( $p < 0.0001$ , Figure 2). The 3-y revision rate was lowest in patients who received a cemented prosthesis (0.9%, 95% CI 0.8%–1.1%) and highest after hip resurfacing (2.6%, 95% CI 2.1%–3.1%). The 3-y revision rate was 2.0% (95% CI 1.7%–2.3%) in patients who received a cementless prosthesis and 1.5% (95% CI 1.1%–2.0%) in patients who received a hybrid. The differences in revision rates among the procedure types were already apparent within 3 mo of the primary procedure.

The pattern of revision rates according to hip prosthesis

**Figure 2.** Survival Rate Estimates for Primary Hip Replacements

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**Table 3.** Primary Hip Replacement: Revision Rates (%) and Multivariable Hazard Ratios (95% CIs) According to Prosthesis Type and Patient Characteristics

Category	Prosthesis Type and Patient Characteristics	Men			Women		
		1-y Revision Rate	3-y Revision Rate	Hazard Ratio	1-y Revision Rate	3-y Revision Rate	Hazard Ratio
Prosthesis type	Cemented	0.5% (0.4%–0.6%)	1.1% (0.8%–1.5%)	1	0.3% (0.2%–0.4%)	0.8% (0.7%–1.0%)	1
	Cementless	1.0% (0.8%–1.3%)	2.4% (1.9%–3.1%)	2.3 (1.7–3.1)	1.0% (0.8%–1.2%)	1.6% (1.3%–2.0%)	2.7 (2.1–3.6)
	Hybrid	0.9% (0.6%–1.3%)	1.9% (1.3%–2.6%)	1.8 (1.3–2.6)	0.6% (0.4%–0.8%)	1.2% (0.7%–1.9%)	1.6 (1.1–2.2)
	Resurfacing	1.5% (1.1%–2.5%)	1.9% (1.4%–2.5%)	2.8 (1.9–4.0)	1.9% (1.4%–2.6%)	3.7% (2.8%–5.0%)	6.0 (4.1–8.9)
<b>p-Value</b>	—	—	<0.0001	—	—	<0.0001	
Age	<55 y	0.9% (0.7%–1.3%)	1.7% (1.3%–2.3%)	1	0.8% (0.5%–1.1%)	1.8% (1.4%–2.5%)	1
	55–64 y	1.0% (0.8%–1.2%)	1.9% (1.5%–2.5%)	1.3 (0.9–1.9)	0.9% (0.7%–1.1%)	1.7% (1.3%–2.1%)	1.4 (1.0–2.0)
	65–74 y	0.7% (0.5%–0.9%)	1.6% (1.2%–2.0%)	1.2 (0.8–1.8)	0.5% (0.4%–0.6%)	1.0% (0.8%–1.4%)	1.2 (0.8–1.8)
	75+ y	0.7% (0.5%–0.9%)	1.3% (0.9%–2.1%)	1.3 (0.8–2.0)	0.4% (0.3%–0.6%)	0.9% (0.7%–1.2%)	1.2 (0–1.8)
<b>p-Value</b>	—	—	0.5	—	—	0.3	
Indication for surgery	Osteoarthritis	0.8% (0.7%–0.9%)	1.5% (1.3%–1.8%)	1	0.6% (0.5%–0.7%)	1.1% (1.0%–1.3%)	1
	Other	1.2% (0.8%–1.9%)	3.1% (1.9%–5.0%)	1.9 (1.3–2.8)	0.8% (0.5%–1.2%)	2.4% (1.5%–3.7%)	1.9 (1.3–2.6)
<b>p-Value</b>	—	—	0.004	—	—	0.0009	

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type was related to the patients' sex ( $p$ -value for interaction between prosthesis type and sex: 0.001), but not to age ( $p$ -value for interaction between prosthesis type and age: 0.3). Therefore, we analysed the revision rates separately for men and women. Revision rates were especially increased in women who had undergone a resurfacing compared to those who had received a cemented prosthesis (multivariable hazard ratio 6.0, 95% CI 4.1–8.9; Table 3). Revision rates were also increased in men who had undergone a resurfacing but to a lesser extent (hazard ratio 2.8, 95% CI 1.9–4.0).

We also found that the revision rate was about twice as high in patients who had had a hip replacement for other indications than osteoarthritis. There was no evidence that the revision rates varied according to the patients' age.

### Revision Rates after Knee Replacement

80,697 patients had undergone a primary knee replacement. Of these patients, 68,904 (85%) had received a cemented prosthesis, 5,905 (7%) a cementless prosthesis, 1,178 (1%) a hybrid, 4,110 (5%) a unicompartmental prosthesis, and 600 (0.7%) a patello-femoral replacement (Table 2). In contrast to patients who had a hip replacement, there was no clear association between the age and sex of the patients undergoing knee replacement and the type of prosthesis used. The indication for surgery is osteoarthritis in 96% and this percentage was similar in each prosthesis group.

The overall revision rate following primary knee replacement was 0.4% (95% CI 0.3%–0.4%) at 1 y and 1.4% (95% CI 1.3%–1.6%) at 3 y. Considering cemented, cementless, and unicompartmental prostheses only, we found that revision rates varied according to the prosthesis type used ( $p < 0.0001$ , Figure 3). The 3-y revision rate was highest in patients who had received a unicompartmental prosthesis (2.8%, 95% CI 1.8%–4.5%). The revision rates in those who had a cemented or cementless prosthesis were similar (1.4%, 95% CI 1.2%–1.5% and 1.5%, 95% CI 1.1%–2.1%, respectively).

There was no evidence that the pattern of revision rates according to the type of knee prosthesis type was related to sex ( $p$ -value for interaction between prosthesis type and sex:

0.6) and there was only weak evidence that it was related to age ( $p$ -value for interaction between prosthesis type and age: 0.09). The revision rates decreased strongly with age and were low for all three types of prosthesis in older patients (Table 4).

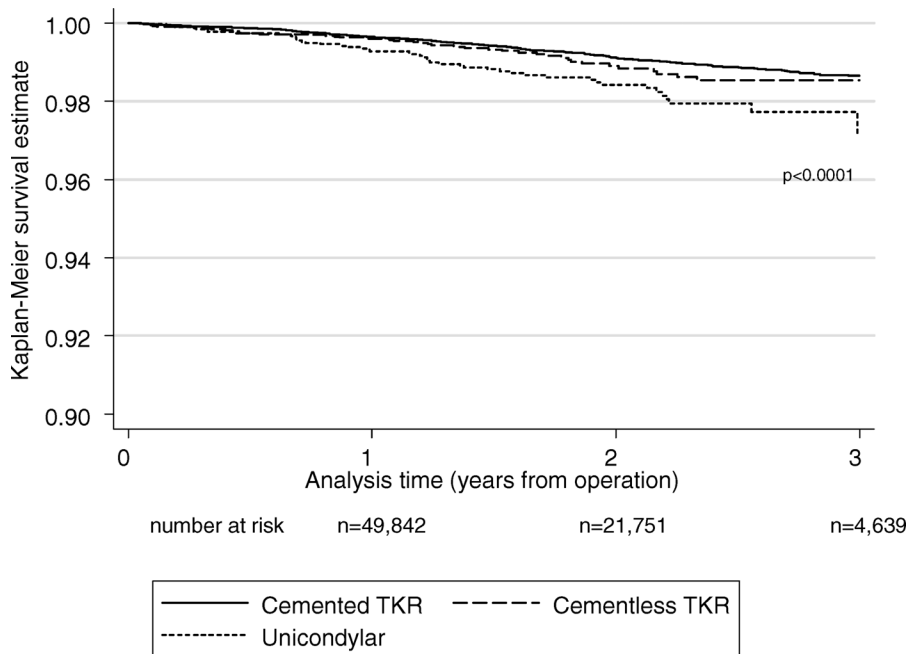
### Discussion

Revision rates in the first 3 y after hip and knee replacements carried out in the NHS in England since April 2003 were low. Overall, we found that about one in 75 patients needed a revision of their joint replacement. Patients who had a cemented hip or cemented knee prosthesis had the lowest revision rates. The highest rates after hip replacement were seen in patients who had undergone hip resurfacing and the highest rates after knee replacement in patients who had a unicompartmental prosthesis. Revision rates after hip resurfacing were especially high in women. It is essential to continue following up these patients to assess whether these differences remain beyond the first 3 y, because it has been shown that risk factors for revision as well as reasons for revision change with time after the joint replacement [26].

### Methodological Limitations

The identification of revisions of primary hip and knee replacement within the HES database may have been incomplete. The completeness of this identification process depends on the following two conditions. First, the revision procedure must have been carried out in the NHS and not in the independent sector. Further explorations within the NJR database only indicated that more than 98% of the revisions were carried out in the NHS. Second, the revisions must be captured by the OPCS-4 codes in the HES database. Given that deficiencies in these codes cannot be excluded, we need to accept that the reported revision rates may be underestimates.

Another limitation is that we could only include 51% of the primary procedures carried out in the NHS. This percentage was low because the NJR only started in 2003 and case ascertainment and the collection of patient identifiers



**Figure 3.** Survival Rate Estimates for Primary Knee Replacements  
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(needed to link the NJR records with HES records) are gradually improving. However, the differences in age, sex, and indications for surgery between the linked and nonlinked procedures were marginal (unpublished data). Furthermore, and even more importantly, the overall revision rates following the primary hip and knee replacements in the NHS that could not be included was 1.5%, and the corresponding figure following a primary knee replacement was 1.6%. These revision rates are very similar to those observed in patients who were included, which supports our conclusion that the observed results are representative at a national level.

The clinical characteristics of the patients and their joint problem will partly determine the choice of prosthesis type. For example, cemented prostheses are generally implanted in older and less active patients whereas cementless prostheses are used in the youngest and most active ones. Therefore, we took differences in patient characteristics into account when comparing revision rates according to prosthesis type by carrying out multivariable regression analyses. However, there was little overlap between the distribution of patients' age and sex of some of the prosthesis types. As a consequence, we have to accept that some of the adjusted differences in revision rates according to prosthesis type are due to

**Table 4.** Primary Knee Replacement: Revision Rates (%) and Multivariable Hazard Ratios (95% Confidence Intervals) According to Prosthesis Type and Patient Characteristics

Category	Prosthesis Type and Patient Characteristics	1-y Revision Rate	3-y Revision Rate	Hazard Ratio
<b>Prosthesis type</b>	Cemented	0.4% (0.3%–0.4%)	1.4% (1.2%–1.5%)	1
	Cementless	0.4% (0.3%–0.6%)	1.5% (1.1%–2.1%)	1.2 (0.9–1.6)
	Unicondylar	0.7% (0.5%–1.1%)	2.8% (1.8%–4.5%)	1.7 (1.2–2.2)
<b>p-Value</b>	—	—	—	0.006
<b>Age</b>	<55 y	0.6% (0.4%–1.0%)	3.0% (2.1%–4.4%)	1
	55–64 y	0.5% (0.4%–0.6%)	2.3% (1.9%–2.8%)	0.8 (0.6–1.1)
	65–74 y	0.4% (0.3%–0.5%)	1.2% (1.0%–1.5%)	0.5 (0.4–0.7)
	75+ y	0.3% (0.2%–0.4%)	1.0% (0.8%–1.2%)	0.4 (0.3–0.6)
<b>p-Value</b>	—	—	—	<0.0001
<b>Sex</b>	Men	0.5% (0.4%–0.6%)	1.8% (1.5%–2.1%)	1
	Women	0.3% (0.3%–0.4%)	1.2% (1.0%–1.4%)	0.7 (0.6–0.8)
<b>p-Value</b>	—	—	—	0.0001
<b>Indication for surgery</b>	Osteoarthritis	0.4% (0.3%–0.4%)	1.4% (1.3%–1.6%)	1
	Other	0.5% (0.3%–0.9%)	1.5% (0.8%–2.6%)	1.1 (0.7–1.7)
<b>p-Value</b>	—	—	—	0.8

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**Table 5.** Hip and Knee Revision Rates (95% CIs) in Other National Registries

Replacement	Registry	Prosthesis Type	Time Period	<i>n</i>	1 y	3 y	Definition of Revision
Hip	Norwegian	Cemented	2000–2005	—	—	1.8%	Exchange or removal of femur, femoral head, acetabulum, all components, or complete arthrodesis.  Revision procedures are categorised as major or minor. A major revision involves removal and/or replacement of either femoral stem or acetabular cup or shell. A minor revision is a revision where a major component has not been removed or replaced. Examples of this include exchange of femoral head and or acetabular insert.  A revision is a new operation in a previously replaced hip joint during which one of the components are exchanged, removed, manipulated, or added. It includes excision arthroplasty and amputation, but not a soft tissue procedure.  Revisions are defined as removal, addition, and exchange of components. Re-operations such as lavage or synovectomy are not registered as revisions if some part (typically a polyethylene inlay) has not been exchanged/removed during the operation.  Revision procedures are categorised as major or minor. A major revision involves the removal and/or replacement of a major component. This is defined (with the exception of the patella) as a component that interfaces with bone i.e., either the femoral and/or tibial component. A minor revision is a revision where a major component has not been removed or replaced. Examples of this include patella replacement, tibial insert exchange, or both.  Revision is defined as a new operation in a previously replaced knee joint during which one or more of the components are exchanged, removed, manipulated, or added. It includes arthrodesis or amputation, but not a soft tissue procedure.
		Cementless	2000–2005	—	—	2.6%	
	Australian	Cemented	1999–2005	12,494	1.11% (0.93%–1.32%)	2.14% (1.87%–2.46%)	
		Cementless	1999–2005	42,937	1.71% (1.58%–1.84%)	2.79% (2.61%–2.98%)	
		Hybrid	1999–2005	29,441	1.45% (1.32%–1.60%)	2.38% (2.18%–2.59%)	
Resurfacing	1999–2005	7,205	1.98% (1.67%–2.35%)	3.12% (2.67%–3.64%)			
	New Zealand	All primary hips	1999–2005	35,998	0.3% (–)	1.2% (–)	
Knee	Swedish	Total knee replacement of osteoarthritis	1995–2004	48,838	0.81% (0.73%–0.90%)	2.36% (2.21%–2.55%)	
		Total knee replacement for rheumatoid arthritis	1995–2004	4,130	0.83% (0.59%–1.16%)	2.53% (2.06%–3.17%)	
		Unicondylar knee replacement of osteoarthritis	1995–2004	9,755	1.46% (1.23%–1.73%)	4.95% (4.5%–5.49%)	
	Australian	Total knee replacement	1999–2005	107,802	1.05% (0.99%–1.12%)	2.84% (2.71%–2.96%)	
		Unicondylar knee replacement	1999–2005	18,398	2.37% (2.15%–2.62%)	6.24% (5.83%–6.69%)	
	New Zealand	All primary knees	1999–2005	23,565	0.3% (–)	1.7% (–)	

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differences in the age and sex distribution as well as to clinical characteristics that were not included in the multi-variable model.

It has been suggested that the results of hip resurfacing and unicondylar knee replacement strongly depend on the surgeons' experience with this technique [27,28]. A possible explanation for the increased revision rates after these procedures is that some surgeons who operated on patients included in our study were still on a "learning curve." However, we compared 1-y revision rates in patients who received these prostheses in 2003, in 2004, and in 2005 or 2006 and did not find evidence that the revision rates decreased with time (1.3%, 1.3%, and 1.9% after hip resurfacing and 0.6%, 0.6%, and 0.9% after unicondylar

knee replacement, respectively; *p*-values for both prostheses, 0.3).

### Comparison with Other National Registries

A number of national registries have published quantitative figures on revision rates in patients who had a hip and knee replacement since 2000 (Table 5) [14–17]. The revision rates observed in Norway and Australia are distinctly higher than those observed in England, whereas those observed in New Zealand are very similar. There are several possible explanations for these differences. First, the completeness of the identification of revisions might be higher in Norway and Australia than in England and New Zealand. Second, the definitions of what constitutes a revision may differ between the registries. For example, the NJR explicitly excludes re-

operations other than revisions [29], whereas the Australian registry explicitly includes minor revisions (revisions that do not include the removal of a component that interfaces with bone with the exception of the patella) [15]. Third, data validation procedures in some of these registries that check the completeness of the reporting of revisions may lead to selective inclusion of patients who had a revision, which may lead to overestimates of the revision rate. In our analyses, we aimed to avoid this bias by only considering revisions that had a record of the primary replacement in the linked NJR-HES database. Before we can come to any conclusions on international differences in revision rates and in turn on the quality of joint replacement care, these possible methodological explanations need to be explored in more detail.

### Hip Resurfacing

The National Institute for Health and Clinical Excellence (NICE) recommended in 2002 that hip resurfacing should be considered as an option for patients with advanced hip disease who are likely to live longer than the expected lifespan of a conventional joint prosthesis [30]. Since then, more evidence has become available, and resurfacing was also approved for use in the United States in 2006 [7,15,31]. Our results on hip resurfacing, the most recent series to date large enough to allow age and sex specific comparisons with other prosthesis types, indicated that revision rates after resurfacing are higher in women, confirming findings of the Australian joint registry [15]. On the basis of these data, resurfacing seems to be more suited for male than for female patients.

### Unicondylar Knee Replacement

A recent systematic review found no differences in the revision rates after unicondylar knee replacement and total knee replacement, but this review was limited by the quality and quantity of the available evidence [9]. We found higher revision rates after unicondylar than after total knee replacement, similar to other national registries [15,17,28]. However, revision rates after knee replacement decreased strongly with age and consequently in elderly patients the absolute differences in revision rates according to prosthesis types are small [14,15].

Unicondylar knee replacement is often recommended because it is thought to be linked to shorter hospital and recovery periods, and to produce superior functional outcomes [32,33]. However, in a sample from the NJR of 10,000 patients 1 y after their knee replacement in 2003, it was found that patients with a unicondylar knee replacement were less likely to be satisfied with their joint replacement than patients with a cemented total knee replacement (odds ratio 0.6, 95% CI 0.4–0.8, based on multivariable regression) [34]. Given these results, further research is required that ideally should include patient-reported outcomes to establish what type of patients are the best candidates for unicondylar replacements.

### Cemented and Cementless Hip Prostheses

A recent meta-analysis compared revision rates after cemented and cementless total hip replacement [35]. This meta-analysis included 20 studies of which three were randomised clinical trials. Considering revisions of either or both components, this study suggested that results depended

on the age of the patients showing lower revision rates with cemented than with cementless prostheses in patients of 55 y and older and no difference in the younger ones. However, we did not find evidence for such an interaction between prosthesis type and age.

### Further Implications

The most up-to-date revision rates reported by the NJR and other national registries should be used as benchmarks against which the performance of new prosthesis designs and brands can be compared. This would also imply that the benchmark revision rate set by National Institute for Health and Clinical Excellence (NICE) for hip prostheses, now set at 10% or less at 10 y [30], from which a 3-y benchmark of 3% is derived [36], may have to be adjusted downwards.

Furthermore, our results demonstrate that linking clinical and administrative databases has the potential to improve the quality and completeness as well as the efficiency of national data collection. Record linkage might also provide additional data on physical activity levels, smoking, and alcohol use, which would allow a study of the impact of lifestyle factors on revision rates.

High-quality national registries allow immediate evaluation of the outcome of the ongoing technological innovations of orthopaedic practice [37]. They would also provide a structure within which randomised controlled trials can be designed and carried out to directly compare benefits and harms of the different prosthesis types and brands. An important consideration is that all these comparisons should contain enough patients that subgroup analyses according to age and sex are possible. Ideally, national joint replacement registries would harmonise their data collection procedures and definitions so that results from different countries with their different orthopaedic cultures can be truly compared and pooled.

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Members of the Steering Committee of the NJR for England and Wales: William Darling, Chair; Paul Gregg, Vice Chair (consultant orthopaedic surgeon); Martyn Porter (consultant orthopaedic surgeon); Keith Tucker (consultant orthopaedic surgeon); Patricia Durkin (patient representative); Michael Borroff (orthopaedic device industry); Anthony Lowther (orthopaedic device industry); Carolyn Naisby (practitioner with special interest in orthopaedics); Mary Cowern (patient representative); Alex MacGregor (public health and epidemiology); Andrew Woodhead (NHS Trust management); Patricia Cassidy (independent healthcare sector). In attendance of the Steering Committee of the NJR for England and Wales: Andy Smallwood (NHS Supply Chain); Andy Crosbie (Medicines and Healthcare Products Regulatory Agency); Ramila Mistry (Department of Health); Kate Wortham (Department of Health); Christine Miles (Welsh Assembly Government).

**Competing Interests:** MB: Chair of ABHI Orthopaedics Special Interest Section; currently employed by DePuy International Ltd, manufacturer of orthopaedic prostheses. PG: Consultant orthopaedic

surgeon, South Tees Hospitals NHS Trust. Unit receives research/audit funding from DePuy International Ltd, Stryker UK, and Smith & Nephew plc. Orthopaedic advisor for Capio Healthcare. AJM: Professor of chronic disease epidemiology, University of East Anglia. Consultant rheumatologist, Norfolk and Norwich University Hospital NHS Trust. M Pickford: Managing director of Accentus Medical and consultant to Northgate Informations Systems, the current contractor for the NJR. Does not receive any direct payment from any orthopaedic manufacturer or other third party. M Porter: Consultant orthopaedic surgeon, Wroughtington, Wigan and Leigh NHS Trust. Works at a unit that has received financial support from DePuy International for clinical and RSA studies for Elite Plus femoral stem and C-stem. Has acted as consultant to DePuy International for development of a hip femoral stem (C-stem AMT). KT: Consultant orthopaedic surgeon, Norfolk and Norwich University Hospital NHS Trust. Various sources of financial support for research undertaken by orthopaedic department. Paid royalties by Johnson and Johnson Orthopaedic more than 5 y ago for contribution to design of hip prostheses. All royalties paid to orthopaedic charity. NS, LPC, JDL, and JHvdM declare that they have no competing interests.

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## Editors' Summary

**Background.** Though records show attempts to replace a hip date back to 1891, it was not till the 1960s before total hip replacements were successfully performed, and the 1970s before total knee replacements were carried out. These procedures are some of the most frequently performed surgical operations, with a total of 160,00 total hip and knee replacement procedures carried out in England and Wales and about half a million in the US in 2006. Hip and knee replacements are most commonly used as a treatment for severe arthritis once other approaches, such as pain relief medications, have failed. A total hip replacement involves replacing the head of the femur (the thigh bone) with an artificial component, typically metal; the socket into which the new femur head will insert is also replaced with artificial components. In an alternative procedure, resurfacing, rather than replacing the entire joint, the diseased surfaces are replaced with metal components. This procedure may be better suited to patients with less severe disease, and is also thought to result in quicker recovery. The techniques for hip and knee replacement can also be divided into those where a cement is used to position the metal implant into the bone (cemented) versus those where cement is not used (cementless).

**Why Was This Study Done?** To date, little evidence has been available to compare patient outcomes following hip or knee replacement with the many different types of techniques and prostheses available. National registries have been established in a number of countries to try to collect data in order to build the evidence base for evaluating different types of prosthesis. Specifically, it is important to find out if there are any important differences in revision rates (how often the hip replacement has to be re-done) following surgery using the different techniques. In England and Wales, the National Joint Registry (NJR) has collected data on patient characteristics, types of prostheses implanted, and the type of surgical procedures used, since its initiation in April 2003.

**What Did the Researchers Do and Find?** The researchers linked the records of the NJR and the Hospital Episode Statistics (HES) for patients treated by the NHS in England who had undergone a primary hip and knee replacement between April 2003 and September 2006. The HES database contains records of all admissions to NHS hospitals in England, and allowed the researchers to more accurately identify revisions of procedures that were done on patients in the NJR database.

They identified 327,557 primary hip or knee replacement procedures performed during that time period, but only 167,076 could be linked between the two databases.

76,576 patients in the linked database had undergone a primary hip replacement. The overall revision rate was 1.4% (95% confidence interval [CI] 1.2%–1.5%) at 3 years, with the lowest revision rates experienced by patients who had cemented prostheses. Women were found to have higher revision rates after hip resurfacing, and the revision rate was

about twice as high in patients who had had a hip replacement for other indications than osteoarthritis. A patient's age did not appear to affect revision rates after hip surgery.

80,697 patients in the linked database had undergone a primary knee replacement. The overall revision rate was 1.4% (95% CI 1.3%–1.6%) at three years, again with the lowest rates of replacement experienced by patients who had cemented prostheses. Revision rates after knee replacement strongly decreased with age.

**What Do These Findings Mean?** Overall, about one in 75 patients required a revision of their joint replacement, which is considered low, and cemented hip or knee prosthesis had the lowest revision rates. Post hip replacement, the highest revision rate was in patients who had undergone hip resurfacing, especially women. Following knee replacement, the highest revision rate was in patients who had undergone unicompartmental prosthesis. However, in this study patients were only followed up for three years after the initial knee replacement, and it's possible that different patterns regarding the success of these differing techniques may emerge after longer follow-up. Importantly, this study was entirely observational, and data were collected from patients who had been managed according to routine clinical practice (rather than being randomly assigned to different procedures). Substantial differences in the age and clinical characteristics of patients receiving the different procedures were seen. As a result, it's not possible to directly draw conclusions on the relative benefits or harms of the different procedures, but this study provides important benchmark data with which to evaluate future performance of different procedures and types of implant.

**Additional Information.** Please access these Web sites via the online version of this summary at <http://dx.doi.org/10.1371/journal.pmed.0050179>.

- The website of the British Orthopaedic Association contains information for patients and surgeons
- The website of the National Institute for Health and Clinical Excellence contains guidance on hip prostheses
- Information is available from the US National Institutes of Health (Medline) on hip replacement, including interactive tutorials and information about rehabilitation and recovery
- Medline also provides similar resources for knee replacement
- The NHS provides information for patients on hip and knee replacement, including questions patients might ask, real stories, and useful links
- The National Joint Registry provides general information about joint replacement, as well as allowing users to download statistics on the data it has collected on the numbers of procedures carried out in the UK