Adverse outcomes after total and unicompartmental knee replacement in 101 330 matched patients: a study of data from the National Joint Registry for England and Wales

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Summary

Background Total knee replacement (TKR) or unicompartmental knee replacement (UKR) are options for end-stage osteoarthritis. However, comparisons between the two procedures are confounded by differences in baseline characteristics of patients undergoing either procedure and by insufficient reporting of endpoints other than revision. We aimed to compare adverse outcomes for each procedure in matched patients.

Methods With propensity score techniques, we compared matched patients undergoing TKR and UKR in the National Joint Registry for England and Wales. The National Joint Registry started collecting data in April 1, 2003, and is continuing. The last operation date in the extract of data used in our study was Aug 28, 2012. We linked data for multiple potential confounders from the National Health Service Hospital Episode Statistics database. We used regression models to compare outcomes including rates of revision, revision/reoperation, complications, readmission, mortality, and length of stay.

Findings 25 334 UKRs were matched to 75 996 TKRs on the basis of propensity score. UKRs had worse implant survival both for revision (subhazard ratio [SHR] 2·12, 95% CI 1·99–2·26) and for revision/reoperation (1·38, 1·31–1·44) than TKRs at 8 years. Mortality was significantly higher for TKR at all timepoints than for UKR (30 day: hazard ratio 0·23, 95% CI 0·11–0·50; 8 year: 0·85, 0·79–0·92). Length of stay, complications (including thromboembolism, myocardial infarction, and stroke), and rate of readmission were all higher for TKR than for UKR.

Interpretation In decisions about which procedure to offer, the higher revision/reoperation rate of UKR than of TKR should be balanced against a lower occurrence of complications, readmission, and mortality, together with known benefits for UKR in terms of postoperative function. If 100 patients receiving TKR received UKR instead, the result would be around one fewer death and three more reoperations in the first 4 years after surgery.

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Introduction

Total knee replacement (TKR), usually undertaken for end-stage osteoarthritis, is one of the commonest surgical procedures, with more than 76 000 TKRs done every year in the UK.[1] International trends suggest that this number will rise substantially, largely because of the ageing population and an increased prevalence of risk factors, including obesity.[2]

TKR is a highly successful and cost-effective procedure. In terms of implant survival, more than 95% are in situ 10 years after surgery.[1,3,4] However, implant survival is an imperfect measure. With this measure, patients who have died, those who undergo reoperations that are not regarded as revisions (such as debridement for infection or manipulation under anaesthetic for stiffness), and those who have poorly functioning, but unrevised, knee replacements, are all classed as successes.[5]

The proportion of TKRs that is judged successful changes with the use of different outcome measures. 90-day mortality after TKR is 0·4%,[6] by 4 years, 3·8% of patients undergo a non-revision reoperation;[7] 8·5% of patients have worse patient-reported outcome measures 6 months after knee replacement than they had beforehand;[8] and up to 20% are dissatisfied after TKR.[9]

A large proportion of patients who are eligible for TKR are also eligible for unicompartmental knee replacement (UKR) in which only the parts of the knee affected by osteoarthritis are replaced.[10,11] Better patient reported outcomes can be obtained with UKR than with TKR, and mortality and major complications are lower after UKR than after TKR.[4,12] However, unadjusted data from national registries show a significantly higher revision rate for UKR than for TKR.[1,3,4] Because revision rate has traditionally been regarded as the most important factor to determine implant choice, only 8% of knee replacements done each year in the UK are UKRs, and most knee surgeons do not do them.

As such, the use of UKR in the treatment of end-stage osteoarthritis is controversial. Fair comparison of TKR and UKR is hampered by differences in the baseline characteristics of patients being offered each procedure

	Crude		p value	Matched*	
	TKR	UKR		TKR	UKR
Number of patients	315 767	25 982		75 996	25 334
Age at surgery (years)	70·4 (9·1)	64·3 (9·7)	<0·0001	64·7 (9·3)	64·7 (9·4)
Unit type					
Public hospital	269 857 (86%)	22 085 (85%)	0·044	64 179 (85%)	21 544 (85%)
Independent hospital	33 542 (11%)	2872 (11%)	0·030	9141 (12%)	2801 (11%)
Independent sector treatment centre	12 368 (4%)	1025 (4%)	0·822	2676 (4%)	989 (4%)
Thromboprophylaxis					
Drugs					
Unfractionated or low molecular weight heparin	209 221 (66%)	15 816 (61%)	<0·0001	48 546 (64%)	15 438 (61%)
Aspirin	34 668 (11%)	3924 (15%)	<0·0001	9519 (13%)	3858 (15%)
Warfarin	3447 (1%)	211 (1%)	<0·0001	727 (1%)	208 (1%)
Direct thrombin inhibitor	12 487 (4%)	1101 (4%)	0·025	2654 (4%)	1050 (4%)
Other	23 410 (7%)	1927 (7%)	0·986	5205 (7%)	1830 (7%)
None/unspecified	32 514 (10%)	3003 (12%)	<0·0001	9345 (12%)	2950 (12%)
Mechanical					
Thromboembolic deterrent stockings	203 878 (65%)	16 772 (65%)	0·965	49 246 (65%)	16 323 (64%)
Foot pumps/intermittent calf compression	67 884 (22%)	5820 (22%)	0·001	16 686 (22%)	5653 (22%)
Other	4129 (1%)	272 (1%)	<0·0001	1012 (1%)	266 (1%)
None/unspecified	39 876 (13%)	3118 (12%)	0·003	9052 (12%)	3092 (12%)
Indices of multiple deprivation (quintiles)[13]					
1	48 598 (15%)	2951 (11%)	<0·0001	8744 (12%)	2915 (12%)
2	59 609 (19%)	4361 (17%)	<0·0001	12 247 (16%)	4291 (17%)
3	70 398 (22%)	5791 (22%)	0·983	16 723 (22%)	5666 (22%)
4	71 870 (23%)	6179 (24%)	<0·0001	19 070 (25%)	5986 (24%)
5	65 292 (21%)	6700 (26%)	<0·0001	19 212 (25%)	6476 (26%)
Hypertension	140 581 (45%)	8926 (34%)	<0·0001	26 542 (35%)	8851 (35%)
Sex (male)	135 515 (43%)	13 547 (52%)	<0·0001	39 573 (52%)	13 106 (52%)
Fixation					
Cemented	285 749 (91%)	23 407 (90%)	0·033	68 776 (91%)	22 822 (90%)
Uncemented	26 135 (8%)	1 944 (8%)	<0·0001	5684 (8%)	1912 (8%)
Hybrid	3883 (1%)	631 (2%)	<0·0001	1536 (2%)	600 (2%)
Ethnic origin					
Undefined	38 832 (12%)	3654 (14%)	<0·0001	9983 (13%)	3593 (14%)
White	263 333 (83%)	21 506 (83%)	0·010	63 547 (84%)	20 934 (83%)
Mixed race	615 (<1%)	54 (<1%)	0·647	114 (<12%)	51 (<1%)
Asian	8587 (3%)	515 (2%)	<0·0001	1643 (2%)	511 (2%)
Black	2992 (1%)	120 (1%)	<0·0001	471 (1%)	116 (1%)
Other	1408 (1%)	133 (1%)	0·127	238 (<1%)	129 (1%)
Cases done by consultant	231 151 (73%)	22 255 (86%)	<0·0001	64 998 (86%)	21 628 (85%)
Cases per consultant per year	73·9 (52·5)	85·7 (56·6)	<0·0001	84·7 (58·8)	84·8 (55·5)
Comorbidities (Charlson index)[14]					
None	240 663 (76%)	20 865 (80%)	<0·0001	60 935 (80%)	20 291 (80%)
Mild	60 152 (19%)	4298 (17%)	<0·0001	12 560 (17%)	4233 (17%)
Moderate	11 389 (4%)	642 (3%)	<0·0001	1988 (3%)	635 (3%)
Severe	3563 (1%)	177 (1%)	<0·0001	513 (1%)	175 (1%)
American Society of Anesthesiologists score[15]					
1	36 461 (12%)	5885 (23%)	<0·0001	16 050 (21%)	5463 (22%)
2	228 079 (72%)	17 725 (68%)	<0·0001	53 268 (70%)	17 507 (69%)
3+	51 227 (16%)	2372 (16%)	<0·0001	6678 (9%)	2364 (9%)

Data are n (%) or mean (SD). TKR=total knee replacement. UKR=unicompartmental knee replacement. *No significant differences after matching.

Table 1: **Baseline and matched demographics**

(known as confounding by indication); for instance, UKR is often offered to younger patients who, because of their higher activity levels, tend to have better functional outcomes, but increased failure rates.[1,3,4]

The aim of this study was to comprehensively compare the rates of adverse outcomes after TKR and UKR, with large datasets from the National Joint Registry for England and Wales (NJR), Hospital Episode Statistics (HES), and the Office for National Statistics (ONS). We have studied multiple outcomes, including complications, readmission, reoperation, and death.

Methods

Data source

We analysed NJR records linked to data from the HES database. The NJR began collecting data in 2003 and contains details of more than 1 million joint replacements, making it the largest joint registry in the world.[1] For this study, we extracted data for all knee replacements done between the start of data collection on April 1, 2003, and Aug 28, 2012. Where possible, we linked these data to corresponding records in the HES database. Records could be linked to HES if they took place in, or were funded by, an NHS trust in England. HES provides additional information for every patient (including detailed comorbidity information and deprivation indices), and about every procedure (including length of stay and need for blood transfusion or critical care). Additional linked records contain details of readmissions, reoperations, and revisions not recorded in the NJR database. Data for all-cause mortality are provided by the ONS; these data are linked periodically to the NJR database. The data used here were extracted from the NJR shortly after the latest NJR–ONS linkage. Patients consent for their data to be collected from the NJR. The National Information Governance Board (now the Confidentiality Advisory Group) gave us permission to link the datasets (application number ECC 1-02 (FT3)/2013). We consulted the National Research Ethics Service who confirmed that we did not need local research ethics committee approval.

Procedures

We did analyses to compare the outcomes of TKR and UKR by six measures: rates of revision, revision/reoperation, and readmission; length of stay, complications of surgery, and mortality. To address the problem of confounding by indication, we have matched patients with propensity scoring techniques. We compared the reasons for revision (as reported by the operating surgeon) and the revision operation (exchange of modular components or secondary patellar resurfacing, conversion to primary TKR, complex revision) for the two procedures. Complex revisions were defined as revisions to hinged components or components with stems or wedges, or two-stage procedures. We restricted our analyses to patients older than 18 years undergoing primary knee replacement for osteoarthritis. We excluded patellofemoral replacements, so-called complex primary knee replacements, and primary operations with augmentation and stems (implying a complex deformity). We showed significant differences in baseline characteristics between groups (table 1).

Statistical analysis

We used propensity score matching to generate matched cohorts for comparison.[16] First, we estimated the effects of each confounder on treatment allocation using a logistic regression model. Using these estimates, we generated a score representing the probability of each knee receiving UKR; we matched three TKR patients to every one UKR patient on the basis of this propensity

	Survival for TKR (%; 95% CI)	Survival for UKR (%; 95% CI)	Hazard*/subhazard† ratio (95% CI)	NNT (95% CI)
Revision				
4 years	96·4% (96·2–96·5)	92·7% (92·3–93·1)	1·97 (1·84–2·12)	30·0 (26·1–34·7)
8 years	94·6% (94·2–94·9)	87·0% (86·2–87·9)	2·12 (1·99–2·26)	17·6 (15·6–19·9)
Revision/ reoperation				
Overall	87·2% (86·7–87·8)	80·4% (79·4–81·4)	1·38 (1·31–1·44)	14·7 (13·2–16·6)
0–3 months	..	..	0·46 (0·38–0·56)	..
3 months–8 years	..	..	3·34 (2·75–4·07)	..
Mortality				
30 days	99·76% (99·71–99·81)	99·94% (99·88–99·97)	0·23 (0·11–0·50)	543·6 (467·2–839·6)
90 days	99·53% (99·45–99·59)	99·78% (99·68–99·85)	0·47 (0·31–0·69)	399·0 (309·9–696·7)
1 year	99·22% (99·15–99·28)	99·47% (99·37–99·55)	0·69 (0·58–0·83)	420·2 (303·9–778·2)
4 years	95·66% (95·46–95·84)	96·71% (96·41–96·98)	0·75 (0·68–0·82)	93·5 (75·6–732·7)
8 years	88·52% (87·85–89·16)	89·10% (88·06–90·06)	0·85 (0·79–0·92)	62·1 (43·4–115·5)

Hazard ratios less than 1 favour unicompartmental knee replacement. The revision/reoperation hazard ratios are split because of time-varying hazard (see text); survival and NNT are provided at 8 years. NNT=number needed to treat (ie, number of patients switching treatment to avoid one adverse event). TKR=total knee replacement. UKR=unicompartmental knee replacement. *Hazard ratios are provided for mortality (Cox regression). †Subhazard ratios are provided for revision and revision/reoperation (competing risks regression).

Table 2: **Propensity-score matched survival models by timepoints up to 8 years by outcome**

score. When calculating the propensity score, we included confounders consisting of age, sex, ethnic origin, Charlson comorbidity index, American Society of Anaesthesiologists (ASA) score, Index of Multiple Deprivation (in quintiles and by each subgroup), implant fixation, type of mechanical or chemical thromboprophylaxis, unit type (public, private, independent sector treatment centre), surgical caseload (the combined number of TKRs and UKRs done by the surgeon in charge in the year of surgery), and the grade of the primary surgeon (consultant or trainee). Body-mass index (BMI) had a large proportion of missing data and, we therefore did not include it in the propensity score analysis. As a sensitivity analysis, we calculated estimates for complete case datasets, with and without BMI, and after completing the missing values using multiple imputation (appendix).

See Online for appendix

We used proportional hazards regression to examine survival outcomes (revision, revision/reoperation, and mortality). Because mortality can be regarded as a competing risk for revision surgery, we used competing risk regression when examining revision and revision/reoperation;[17] we used Cox regression for the mortality comparison. We examined continuous outcomes (length of stay) using linear regression and binary outcomes (complications during the primary admission) using logistic regression, and examined readmission rate (within the first year) using a zero-inflated Poisson model.

For the survival models, we tested the proportional hazards assumption using Schoenfeld's residuals. If the proportional hazards assumption was violated, we analysed survival hazards in sections, with breaks being placed at the points of divergence from proportionality. Results of these models are presented as overall survival percentages, hazard ratios, and numbers needed to treat (NNT, representing the number needing to switch from one procedure to the other to avoid one adverse event, calculated with Altman and colleagues'[18] method).

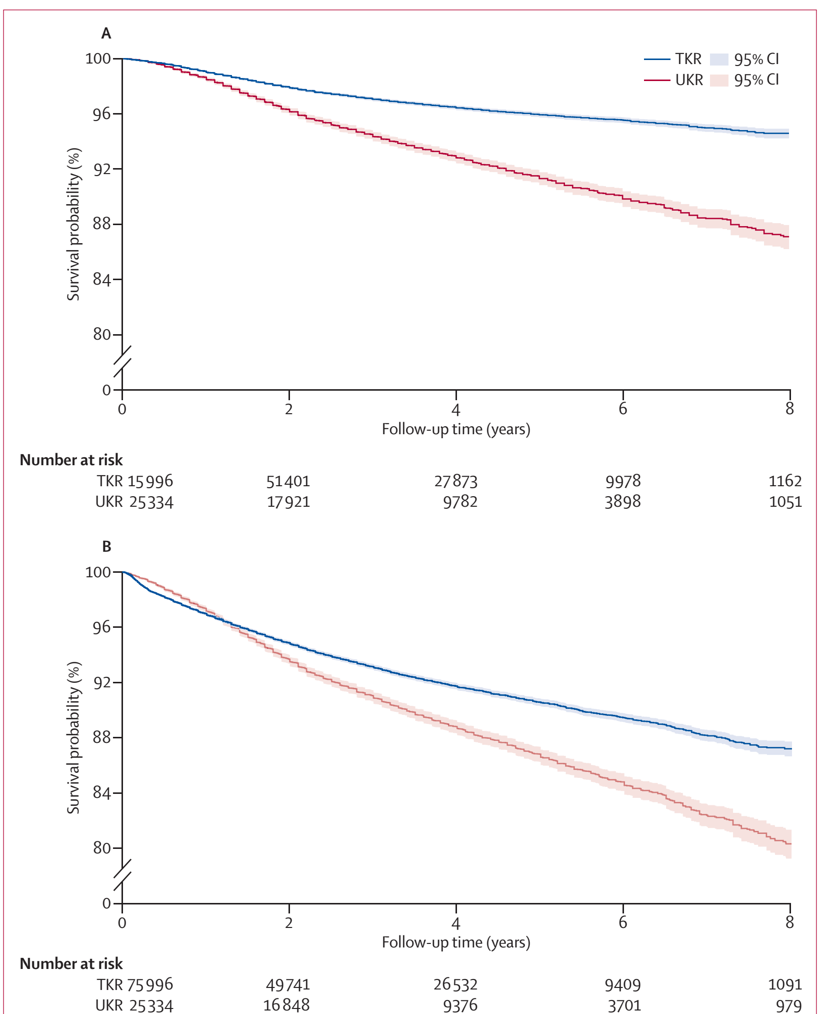

Figure 1: **Kaplan-Meier curve of revision (A) and revision/reoperation (B) to 8 years in matched patients**
UKR=unicompartmental knee replacement. TKR=total knee replacement.

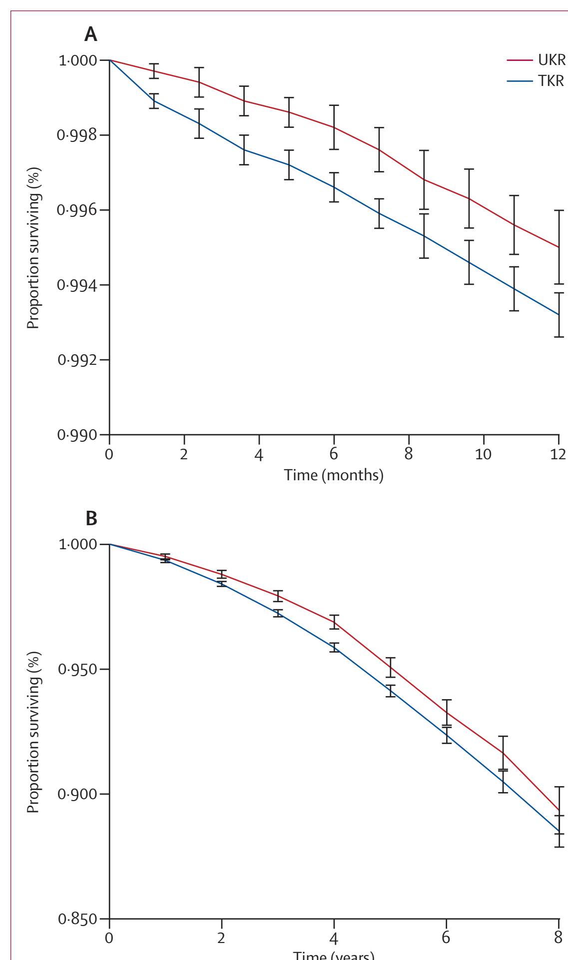

Figure 2: **Survival curves showing comparison of mortality at 1 year (A) and 8 years (B)**
UKR=unicompartmental knee replacement. TKR=total knee replacement. Error bars show 95% CI.

We used Stata (version 12.1) for all statistical analyses, and used R (R Foundation for Statistical Computing, Vienna, Austria) to do the matching on the basis of propensity score.

Role of the funding source

The sponsors of the study had no role in the design or conduct of the study. All authors had full access to the data and take responsibility for the contents of the study and the decision to proceed to publication. DWM is the guarantor.

Results

From a pool of 552 015 records from the NJR, and after exclusion of patellofemoral and complex primary knee replacements, a total of 341 749 records (315 767 TKRs and 25 982 UKRs) could be linked to HES records. We recorded significant differences in several baseline variables (table 1). On the basis of propensity score, 25 334 (98%) of 25 982 UKRs could be matched to TKRs. Because we matched on a ratio of three TKRs to each UKR, the matched study group consisted of 101 330 knees, of which 75 996 were TKRs. After matching, we achieved balance with respect to confounding factors (table 1).

After matching, implant survival at 8 years (with all-cause revision as the endpoint) was greater for TKR than for UKR (table 2, figure 1). Inclusion of all reoperations reduced overall survival values and attenuated the difference between TKR and UKR. At 8 years, implant survival (with revision/reoperation as the endpoint) was greater for TKR than for UKR (subhazard ratio 1·38, 95% CI 1·31–1·44; table 2). The survival hazard for reoperation varied with time. More reoperations were done for TKR than for UKR in the first 3 months before the TKR hazard became shallower and the hazards crossed at around 15 months (figure 2). Therefore, a break was introduced at 3 months; in the first 3 months, the revision/reoperation rate was significantly higher for TKR than for UKR; between 3 months and 8 years the risk of revision/reoperation was significantly higher for UKR than for TKR (table 2).

Mortality was significantly higher for TKR at all timepoints (table 2). At 30 days, 90 of 76 074 patients (cumulative mortality rate 0·24%, 95% CI 0·19–0·29) had died in the TKR group compared with seven of 25 358 (0·06%, 0·03–0·12) in the UKR group. Hazard ratios were 0·23 (0·11–0·50) at 30 days and 0·47 (0·31–0·69) at 90 days. Although the hazard ratio fell with time, the absolute difference in death rates increased to 1·1% (0·7–1·4%) at 4 years, before decreasing to 0·7% (–0·5 to 1·9) at 8 years (figure 2).

Mean length of stay was 1·38 days shorter for UKR than for TKR (mean 5·52 [SD 3·97] for TKR; 4·14 [2·24] for UKR; 95% CI 1·33–1·43, p<0·0001) and readmission within the first year was significantly less likely in UKR than in TKR (incidence rate ratio 0·65, 0·58–0·72). Intraoperative complications, blood transfusion, thromboembolism, stroke, and myocardial infarction were significantly less likely for UKR than for TKR (table 3).

	Crude comparisons		Propensity matched comparisons	
	Odds ratio (95% CI)	p value	Odds ratio (95% CI)	p value
Intraoperative complications	0·70 (0·57–0·87)	0·001	0·73 (0·58–0·91)	0·006
Critical care admission	0·72 (0·60–0·86)	<0·001	0·84 (0·69–1·02)	0·075
Blood transfusion	0·18 (0·12–0·26)	<0·001	0·25 (0·17–0·37)	<0·0001
Thromboembolism	0·42 (0·34–0·52)	<0·001	0·49 (0·39–0·62)	<0·0001
Stroke	0·28 (0·13–0·63)	0·002	0·37 (0·16–0·86)	0·021
Myocardial infarction	0·32 (0·20–0·52)	<0·001	0·53 (0·31–0·90)	0·018

Odds ratios less than 1 favour unicompartmental knee replacement.

Table 3: **Crude and matched logistic models for complications**

	TKR		UKR		Hazard ratio (95% CI)	p value
	Rank	N (%)	Rank	N (%)		
Loosening/lysis	1=	351 (25·1)	1	385 (30·1)	3·17 (2·75–3·67)	<0·0001
Infection	1=	351 (25·1)	7	61 (4·8)	0·50 (0·38–0·66)	<0·0001
Pain	3	152 (10·9)	2	264 (20·6)	5·08 (4·16–6·21)	<0·0001
Instability	4	141 (10·1)	8	58 (4·5)	1·20 (0·88–1·62)	0·254
Malalignment	5	107 (7·7)	6	76 (5·9)	2·04 (1·52–2·75)	<0·0001
Stiffness	6	99 (7·1)	11	12 (0·9)	0·36 (0·20–0·66)	0·001
Other reasons	7	88 (6·3)	4	135 (10·6)	4·40 (3·36–5·76)	<0·0001
Dislocation/dissociation	8	30 (2·2)	5	92 (7·2)	10·01 (6·52–15·38)	<0·0001
Wear	9	30 (2·2)	9	27 (2·1)	2·49 (1·48–4·20)	0·001
Progression of disease	10	27 (1·9)	3	144 (11·3)	15·09 (10·00–22·78)	<0·0001
Periprosthetic fracture	11	15 (1·1)	10	22 (1·7)	4·24 (2·19–8·18)	<0·0001
Implant fracture	12	5 (0·4)	12	3 (0·2)	1·68 (0·40–7·05)	0·478
Total	..	1396	..	1279	..	..

Percentages are the percentage of all revisions that are done for the reason given. Hazard ratios represent the overall risk of being revised for each reason at 8 years. Hazard ratios less than 1 favour unicompartmental knee replacement. TKR=total knee replacement. UKR=unicompartmental knee replacement.

Table 4: **Reasons for revision in unicompartmental knee replacement (UKR) and total knee replacement (TKR; matched analysis, revisions recorded in NJR only)**

Reasons for revision differed between TKR and UKR (table 4). Although aseptic loosening was the commonest reason for revision after either operation, significantly more TKRs than UKRs were revised for infection and stiffness. Progression of arthritis and bearing dislocation are modes of failure that were almost exclusive to UKR, and as a result, the odds ratio for revision for either reason greatly favoured TKR. Unexplained pain, aseptic loosening, malalignment, wear, periprosthetic fracture, and other unspecified reasons for revision were significantly more common in UKR than in TKR. The proportion of patients being revised for instability or implant fracture was much the same for the two operations (table 4).

Although most revisions in TKR required augments or constrained implants, most of those recorded for UKR in the NJR were conversions to a primary TKR. These conversion-type operations accounted for the difference

	TKR			UKR			Hazard ratio (95% CI)	p value
	N	% of revisions	% of all cases	N	% of revisions	% of all cases		
Bearing/patella	259	19%	<1%	81	6%	<1%	0·90 (0·70–1·16)	0·430
Revision to primary total knee replacement	247	18%	<1%	854	67%	3%	10·07 (8·74–11·62)	<0·0001
Complex revision	890	64%	1%	344	27%	1%	1·12 (0·99–1·27)	0·068
Total	1396	..	..	1279	..	..	..	..

Hazard ratios less than 1 favour unicompartmental knee replacement. TKR=total knee replacement. UKR=unicompartmental knee replacement.

Table 5: **Type of revision operation (matched analysis, revisions recorded in NJR)**

in the revision rate between UKR and TKR. The probability of part revisions (including secondary patellar resurfacing in TKR, and bearing exchange in UKR) did not differ between TKR and UKR, nor did they for complex revisions (table 5).

Discussion

This study shows a significantly higher risk of revision/reoperation in patients undergoing UKR than for matched patients undergoing TKR. However, patients undergoing TKR are at increased risk of medical complications; they are twice as likely to have a venous thromboembolism, myocardial infarction, or deep infection, three times as likely to have a stroke, and four times as likely to need blood transfusions. As a result, these patients are four times more likely to die in the first 30 days after surgery and about 15% more likely to die during the first 8 years. Inpatient stays are longer, and readmissions are more likely after TKR than after UKR. Revisions of TKRs are more commonly due to stiffness or infection, whereas revisions of UKR are more usually done for unexplained pain, arthritis progression, or other unspecified reasons. Most revisions of UKR are conversions to a primary TKR, whereas most revisions of TKR are more complex procedures requiring larger components and increased levels of constraint—constrained implants introduce more tibiofemoral conformity to address the instability caused by the loss of the normal soft-tissue and bony constraints during revision knee surgery. Conversion-type operations accounted for all the difference in the revision rate between UKR and TKR.

In patients with disease suitable for TKR or UKR, the decision of which procedure to offer should take into account the advantages and disadvantages of each, both in terms of functional results and of adverse outcomes. Although previous studies have examined functional outcomes, we have focused on adverse outcomes.[19,20] In the short term, UKR has proved to have clear advantages, with reduced hospital stays, complications, readmissions, and mortality; however, it does have the disadvantage of an increased revision and reoperation rate. The difference in revisions largely consists of conversion-type operations, which are similar to a primary TKR. When offered a choice of elective surgical procedures, patients are likely to rate mortality and major complications (such as myocardial infarction and stroke) as the worst possible outcomes. As such, these outcomes should be as, or more, important factors in the decision about which procedure to offer compared with the risk of reoperation/revision. Although revision is a deeply undesirable result after joint replacement, mortality after elective surgery is devastating.

Revision, reoperation, and death are uncommon outcomes of either procedure. At 4 years, the NNT to avoid a revision is 30 cases and to avoid a death is 93, whereas 8 years the NNT to avoid a revision is 18 cases and to avoid a death is 62. However, because knee replacement is very common, even small percentage differences affect large numbers of patients. Although estimates of the proportion of patients eligible for UKR vary (and have been estimated at up to 47%[10]), a conservative estimate from a previous study[11] suggested that, at present, 21% of patients undergoing TKR meet the criteria for UKR. At 4 years, if 21% of the patients in the NHS currently undergoing TKR underwent UKR instead, a potential annual saving of 169 deaths, at the cost of 405 additional revisions, would result. However, as the revision rate of UKR tends to decrease with increasing surgeon volume, if these surgeons perform more UKRs per year, there might be fewer additional revisions.[21]

The difference in revision rates between UKR and TKR has been well described (panel).[1,3,4] In this study, this difference is smaller than that shown in registry reports (which are unadjusted for patient characteristics)[3,4,11] and observational studies (which have varying degrees of adjustment).[23,24] This difference suggests that patient selection for UKR or TKR exerts a powerful effect on ultimate revision rate. Inclusion of reoperations, which registries do not class as revisions, effaces this effect further. Reasons for the residual difference are multifactorial and include the presence of additional failure mechanisms in UKR (mainly progression of disease), more subtle patient factors (such as the degree of cartilage damage before surgery),[30] and threshold for revision. UKR is easier to revise than TKR, and revision usually results in a primary TKR. As a result, UKR is five times more likely to be revised than a TKR with the same patient-reported outcome.[19]

Differences in mortality between the two procedures have been previously reported;[28] however, as far as we are aware this study is the first to confirm this finding in matched patients and the first to show an effect in the medium term. The reasons for the differences recorded have been discussed in the accompanying paper,[31] but the primary reason is likely to be that UKR surgery is less invasive, both for soft tissue and bone, than is TKR.[12,32] Similar factors explain the findings for perioperative morbidity. In addition to the short-term effect, this study shows that, although the effect of surgery on mortality is attenuated over time, an effect is seen into the medium term. Causality is more difficult to prove at longer follow-up times, but might be related to long-term consequences of complications of surgery, such as myocardial infarction, stroke, venous thromboembolism, or prosthetic joint infection, which we have shown to be more common in TKR than in UKR.

The strengths of this study include the use of an unselected registry sample, reducing the likelihood of sampling bias. The use of linked NJR/HES datasets allows adjustment for a very large set of potential confounders. The use of propensity score matching allows comparison of comparable cohorts and addresses the risk of confounding by indication.[16] This study is the most comprehensively matched study of these two treatments so far.

Weaknesses relate to the observational nature of the study. To address sources of bias, we matched the patients, which raises the possibility that some of the findings, particularly differences in long-term mortality, could result from inadequate matching. If matching were inadequate, then the difference in mortality would be expected to progressively increase over time. However, although the survival curves for mortality diverge progressively for 4 years, they become parallel or converge slightly in the second half of the study, which is what would be expected because medical complications of surgery would only affect mortality for a limited time.

The matching process might also restrict the external validity of the study by excluding unmatchable patients. However, the crude differences between the groups were not large, and 25 329 (97·5%) of 25 982 UKRs could be matched to a TKR. This finding could be attributable to the fact that patients who are eligible for UKR could be offered TKR or UKR, dependent on their surgeon's views, and suggests that the findings shown here might be generalisable to the wider population of patients who are appropriate for UKR.

Propensity score matching has been used for more than 30 years and has gained popularity in diverse specialties of medicine, social sciences, and economics.[33,34] In that time, the understanding of the strengths and limitations of propensity score matching has increased.[35] Although the aim of propensity score matching is to recreate the conditions of a randomised trial in an observational study, this can only be the case if all causes of confounding by indication are eliminated by the matching process (the principle of strong ignorability[33]). In reality, all observational studies will have a degree of unmeasured confounding and the results of propensity score matched studies such as this must be interpreted with this in mind.[35] In this study, patients were matched for 20 variables, and the effect of a 21st, BMI, was examined after matching and shown not to affect outcome (appendix). Potential sources of unmeasured

Panel: Research in context

Systematic review

We searched Medline, Embase, and the Cochrane Library on July 31, 2013, to retrieve all studies comparing unicompartmental knee replacement (UKR) and total knee replacement (TKR) in terms of revision rate, mortality, or complications. Clinical trials and observational studies were included in the review. Additionally, the latest annual reports of six major NJRs (England and Wales, Australia, New Zealand, Sweden, Norway, and Denmark) and one large regional joint registry (Emilia-Romagna, Italy) were retrieved and interrogated. The search identified two randomised trials,[20,22] two retrospective cohort studies,[12,23] and three case-control studies.[24–26] One retrospective study (examining patients with UKR in one knee and TKR in the other) was excluded from the review because it studied a design of UKR that has subsequently been withdrawn as a result of design factors leading to a high revision rate.[27] Only two randomised control trials comparing the two procedures exist. The first, a study of 102 patients at 15 years, reported implant survival at 89·8% (95% CI 74·3–100) for UKR and 78·7% (56·2–100) for TKR, with better functional outcomes with UKR than with TKR.[20] However, substantial attrition was noted, with 45 (44%) of 102 knees in patients who died before 15 years. The second, of 104 knees at very early follow-up, reported better survival with TKR than with UKR at the cost of a higher rate of deep vein thrombosis and a greater fall in haemogolobin concentration with TKR.[22] All major joint registries show a higher revision rate for UKR than for TKR. Unmatched data from the NJR annual report shows hazard ratios between 2·9 and 3·7;[1] similar data from Australia show similar hazard ratios of 2·59 (95% CI 2·50–2·69) and from New Zealand of 2·72 (2·47–2·99).[3,4] Mortality in UKR and TKR has been little studied. The NJR 7th annual report shows hazard ratios of 0·36 (95% CI 0·22–0·58) at 90 days and 0·64 (0·58–0·72) at 5 years, adjusted for age, sex, and American Society of Anaesthesiologists' grade.[28] A large observational study of 2840 TKRs and UKRs adjusted for age, sex, body-mass index, and comorbidities showed significantly increased rates of manipulation under anaesthesia (odds ratio 13, p<0·001), admission to critical care (7·4, p=0·049), and postoperative transfusion (8·5, p=0·036), and for complications overall (2·8, p<0·001).[12] In a smaller study, Lombardi and colleagues[26] reported a shorter length of stay (1·4 days for UKR *vs* 2·2 days for TKR, p<0·001); similar differences are reported in two other small studies.[25,29] In Lyons and colleagues'[23] retrospective cohort study, reduced survival for UKR was reported with an institutional database (5606 TKRs and 279 UKRs, 10 year survival 95% for TKR, 90% for UKR), and in the small case-control study of Amin and colleagues.[24]

Interpretation

Our study is the most comprehensive comparison of UKR and TKR that has been done so far. The NJR is the largest joint replacement database in the world, and our study is the first to address the problem of confounding by indication with propensity score techniques. Most previous comparisons of the two techniques have compared survival alone, and this is the first study to compare TKR and UKR with such a wide selection of endpoints. This study has supported finding of a higher revision and revision/reoperation rate reported by earlier joint registery studies, but has also shown important advantages of UKR in terms of speed of recovery, rate of readmission, ease of revision, morbidity, and mortality. Patient-reported outcomes have not been examined in this study, but previous work has suggested that they could be better in TKR than in UKR. Future studies should examine patient-reported outcomes.

confounding include the radiological stage of disease (patients with only partial loss of cartilage thickness are more prone to revision than those with full-thickness cartilage defects[30]); differences in complexity of operation (although cases with augmentation and those labelled as complex primaries are excluded, there might be more subtle differences between procedures); more detailed patient-level comorbidity data (although reliability of HES comorbidity data are well established[36,37]), and level of preoperative activity. A randomised trial would be required to address these limitations; such a trial is in progress.[38] However, the primary outcomes of this trial are patient-reported outcome measures; the size of a randomised controlled trial that would be required to produce meaningful information about rarer outcomes such as mortality is prohibitive. Such questions are best answered with observational study designs.

The choice of which procedure to offer will depend on the individual patient. Decisions about treatment should be made on the basis of all outcome measures, not merely the revision rate of each procedure. This study should provide important evidence for making such decisions.

Contributors

ADL conceived the study, did the statistical analyses, and drafted the manuscript. AJ contributed substantially to the statistical design and analysis and made major contributions to the writing of the paper. HP made substantial contributions to the conception of the work and the drafting of the manuscript. DWM contributed substantially to the conception and design of the study and made significant revisions to the manuscript. All authors approved the submitted version and agree to be accountable for all aspects of the work.

Declaration of interests

ADL declares that he has no competing interests. HP has been a paid speaker for Biomet, who are manufacturers of orthopaedic implants including unicompartmental and total knee replacements. DWM receives royalties related to the Oxford UKR and is paid consultancy fees by Biomet. AJ has received honoraria from Roche, held advisory board positions (which involved receipt of fees) for Anthera, and received consortium research grants from Servier; none of these entities were related to this study. The Nuffield Department at Oxford receives research funding from Biomet, Stryker, and Zimmer, all of whom are manufacturers of orthopaedic implants. None of these companies were involved in the funding or conduct of this study.

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