

Effect of Surgical Caseload on Revision Rate Following Total and Unicompartmental Knee Replacement

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Background: High-volume surgeons attain the best results following unicompartmental knee replacement (UKR), but the exact relationship between caseload and outcome is not clear. It is not known whether this effect is due to patient selection or surgical skill nor whether a similar effect is seen in total knee replacement (TKR). The aim of this study was to quantify the effect of surgical caseload on survival of both TKR and UKR.

Methods: This study was based on 459,280 patient records (422,149 TKRs and 37,131 UKRs) from the National Joint Registry for England and Wales. The caseload-outcome relationship was characterized graphically and quantified using regression techniques. Patient selection was compared among high, medium, and low-volume surgeons. Prosthetic survival was compared between UKRs (performed by high, medium, and low-volume surgeons) and matched TKRs.

Results: Caseload affected survival of TKR and, more strongly, of UKR. The revision rate following UKR dropped steeply until the volume reached ten cases per year, plateauing at thirty cases. For surgeons performing fewer than ten UKRs per year, the mean eight-year rate of survival of the UKRs was 87.9% (95% confidence interval [CI] = 86.9% to 88.8%) compared with 92.4% (95% CI = 90.9% to 93.6%) for those who performed thirty UKRs or more per year. Analysis of the TKRs showed a linear decrease in revision rate as caseload increased (hazard ratio [HR] for revision = 0.99 [95% CI = 0.98 to 0.99] for every five-case increase in caseload). Surgeons who performed a lower volume of UKRs tended to operate on younger and healthier patients and were more likely to perform revisions to treat loosening and pain. After matching of patients who had undergone UKR with those who had undergone TKR, the surgeons who performed a high volume of UKRs were found to have an eight-year revision/revision rate similar to that seen after TKR (HR for revision or reoperation = 1.10 [95% CI = 0.99 to 1.22] favoring TKR).

Conclusions: This study confirmed the importance of surgical caseload in determining the survival of UKR and, to a lesser extent, TKR. The reasons for this effect are complex and not fully explained by variables recorded in the National Joint Registry; however, the patient selection and revision threshold of lower-volume surgeons may be a factor. Examination of matched patients in this study demonstrated that high-volume surgeons can achieve revision/reoperation rates similar to those observed following TKR.

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

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The use of unicompartmental knee replacement (UKR) remains controversial¹. While it has well-described advantages, including a lower rate of morbidity and mortality²⁻⁴, faster recoveries, and superior patient-reported outcomes⁵⁻⁷, national joint registries have consistently demonstrated UKR to have a higher revision rate than total knee replacement (TKR)^{6,8-11}.

The revision rate after UKR varies among surgeons and units. Long-term studies by high-volume surgeons, from centers involved in designing the prostheses and elsewhere, have reported prosthetic survival rates comparable with those of TKR¹²⁻¹⁶, whereas lower-volume surgeons and national joint registries have reported revision rates more than double that of TKR¹⁷⁻¹⁹. This suggests that the risk factors for revision following UKR are modifiable: if other users of UKR adopt the

same practices as the high-volume users, the advantages of UKR could be gained without paying the price of an unacceptably high revision rate.

Much of the focus on surgical practice related to UKR has concerned surgical caseload: the number of UKRs performed per surgeon (or per unit) per year. Studies of three national joint registries have demonstrated a relationship between the revision rate following UKR and surgical (or unit) caseload^{6,20,21}. However, caseload itself does not predict outcome; rather, it is the expression of other predictors. The most obvious of these is surgical skill; however, low-volume surgeons have reported excellent results with UKR²², and some surgeons who perform a high volume of TKRs have failed to attain acceptable results with UKR²³. Other factors may include revision

TABLE 1 Patient Characteristics in the TKR Group and the UKR Volume Groups

	TKR	UKR		
		<10 Cases/Yr	10 to <30 Cases/Yr	≥30 Cases/Yr
No. (%) of patients	422,149 (91.9)	12,025 (2.6)	14,139 (3.1)	10,967 (2.4)
Mean age (SD) at surgery (yr)	70.4 (9.1)	63.2 (9.4)	64.5 (9.4)	65.7 (10.0)
Male (no. [%])	181,857 (43.1)	6329 (52.6)	7416 (52.5)	5706 (52.0)
Surgery performed by consultant (no. [%])	328,551 (77.8)	10,948 (91.0)	12,825 (90.7)	9440 (77.8)
Mean UKR usage* (SD) (%)	6.0 (10.0)	14.3 (13.5)	26.6 (14.4)	44.6 (18.4)
American Society of Anesthesiologists (ASA) score (no. [%])				
1	55,515 (13.2)	3305 (27.5)	3330 (23.6)	2455 (22.4)
2	303,176 (71.8)	7781 (64.7)	9722 (68.8)	7514 (68.5)
≥3	63,458 (15.0)	939 (7.8)	1087 (7.7)	998 (9.1)
Mean body mass index† (SD) (kg/m ²)	30.6 (5.5)	30.0 (5.0)	30.0 (5.0)	29.8 (5.2)
Unit type (no. [%])				
Public	304,357 (72.1)	8220 (68.4)	9259 (65.5)	6250 (57.0)
Private	94,983 (22.5)	3541 (29.5)	4296 (30.4)	4035 (36.8)
Independent-sector treatment center	22,809 (5.4)	264 (2.2)	584 (4.1)	682 (6.2)
HES linkage (no. [%])	285,234 (67.6)	7566 (62.9)	8903 (63.0)	6381 (58.2)
Charlson comorbidity index‡ (no. [%])				
0	219,230 (76.9)	6152 (81.3)	7195 (80.8)	5041 (79.0)
1	53,427 (18.7)	1200 (15.9)	1439 (16.2)	1129 (17.7)
≥2	12,577 (4.4)	214 (2.8)	269 (3.0)	211 (3.3)
Mean Index of Multiple Deprivation rank (SD)	17,194 (8917.6)	17,857.8 (8845.3)	18,505 (8681.3)	19,718.8 (8643.3)
Race/ethnicity‡ (no. [%])				
White	236,775 (83.0)	6255 (82.7)	7339 (82.4)	5313 (83.3)
Asian	7627 (2.7)	139 (1.8)	175 (2.0)	143 (2.2)
Black	2675 (0.9)	50 (0.7)	26 (0.3)	30 (0.5)
Mixed race	542 (0.2)	16 (0.2)	22 (0.3)	11 (0.2)
Other	1226 (0.4)	39 (0.5)	33 (0.4)	46 (0.7)
Undefined	36,389 (12.8)	1067 (14.1)	1308 (14.7)	838 (13.1)

*The proportion of the surgeon's knee replacements that were UKRs. †Missing for 52.7% of the patients. ‡Values were derived from the HES dataset and so represent proportions of the HES-linked cohort.

TABLE II Outcomes of Regression Model for Survival with Revision* as End Point

Spline Section	HR per 5-Case Increase in Caseload Within Spline Section (95% CI)	
	TKR	UKR
Overall	0.99 (0.98-0.99)	
0-10 cases		0.86 (0.78-0.94)
11-29 cases		0.90 (0.86-0.93)
≥30 cases		1.00 (0.98-1.02)

*As defined by the National Joint Registry.

threshold (surgeons who rarely use UKR may be more ready to perform a revision than high-volume users of UKR)²⁴ and patient selection. Caseload has been found to have a similar effect on the results of TKR, but the magnitude of that effect has not been compared with the effect in UKR²⁵⁻²⁷.

The aim of this study was to answer these questions. The analysis was performed in three parts. First, a descriptive analysis was conducted to delineate the effect of caseload on the survival of UKR and to assess the degree to which this effect is also present in TKR. These data were used to determine evidence-based thresholds to indicate high, medium and low-UKR-caseload groups. In the second analysis, the characteristics of the three caseload groups were compared to determine the extent to which differences in patient selection explain the caseload effect in UKR. In the third analysis, the outcomes of UKR performed by high, medium, and low-volume surgeons were compared with those of matched patients who had undergone TKR.

Materials and Methods

Data Sources

In this study, we used data from two sources, the National Joint Registry for England and Wales and England's Hospital Episode Statistics (HES) database. The National Joint Registry was used as the master database, as it contains the most comprehensive details of the surgical procedures and linked revision data. Patients were matched between databases by using at least three of the following unique identifiers: National Health Service (NHS) identity number, date of birth, sex, and postal code.

The effect of caseload on implant survival was examined using an extract of 552,015 patient records from the National Joint Registry. This sample comprised all primary knee replacements recorded from the National Joint Registry's inception in 2003 to the extraction date (August 2012). Candidates for inclusion were adults who had undergone primary UKR or TKR for osteoarthritis. Patients who underwent patellofemoral replacement or "complex primary" operations, and those with missing operative details, were excluded. As the first and last years of data collection were incomplete, cases from 2003 and 2012 were excluded. The study group comprised 459,280 cases, of which 37,131 (8.1%) were UKRs.

The HES database was used for the analysis of patient factors (in the second part of the study) and the matching of patients for the third part. HES contains information on every inpatient stay in NHS hospitals in England. Patients undergoing surgery in private units or in Wales are not included. As this reduces the number of cases, HES was not used in the descriptive analysis; however, a large amount of additional data is available for patient records linked to HES, allowing very close matching. HES includes detailed socioeconomic and comorbidity data, perioperative complications, and non-revision reoperations.

Exposures and Outcomes

Each surgeon in the National Joint Registry has a specific identifier, used in both private and public hospitals. With use of this identifier, each surgeon's UKR caseload was calculated for each calendar year. The mean caseload (cases per year) for each surgeon was then calculated, excluding the years in which the surgeon performed no UKRs (preventing an artificial reduction in the caseloads of surgeons who started contributing after the start of data collection or who retired or stopped performing UKRs in later years). Each patient was allocated a value representing the caseload of the surgeon who was in charge of his/her operation in the year in which the surgery was performed.

TABLE III Reasons for Revision of UKRs in Low, Medium, and High-Volume Groups

	<10 Cases/Yr			10 to <30 Cases/Yr			≥30 Cases/Yr		
	No.	% of Revisions	% of Cases	No.	% of Revisions	% of Cases	No.	% of Revisions	% of Cases
Aseptic loosening	281	32.4	2.3	181	24.5	1.3	111	29.8	1.0
Unexplained pain	195	22.5	1.6	168	22.7	1.2	53	14.2	0.5
Disease progression	89	10.3	0.7	95	12.9	0.7	50	13.4	0.5
Other	88	10.1	0.7	82	11.1	0.6	46	12.4	0.4
Malalignment	60	6.9	0.5	34	4.6	0.2	17	4.6	0.2
Dislocation	50	5.8	0.4	60	8.1	0.4	41	11.0	0.4
Infection	39	4.5	0.3	38	5.1	0.3	21	5.6	0.2
Instability	36	4.1	0.3	35	4.7	0.2	14	3.8	0.1
Wear	14	1.6	0.1	16	2.2	0.1	7	1.9	0.1
Stiffness	9	1.0	0.1	8	1.1	0.1	3	0.8	0.0
Periprosthetic fracture	7	0.8	0.1	19	2.6	0.1	9	2.4	0.1
Implant fracture	0	0.0	0.0	3	0.4	0.0	0	0.0	0.0

TABLE IV Matched Survival Comparisons

	<10 Cases/Yr		10 to <30 Cases/Yr		≥30 Cases/Yr	
	TKR	UKR	TKR	UKR	TKR	UKR
Matching pool with HES linkage (<i>no.</i>)	285,234	8367	285,234	8903	285,234	6316
No. matched	24,603	8201	26,388	8796	18,672	6224
% matched	8.6	98.0	9.3	98.8	6.5	98.5
Survival rate (95% CI) with revision* only as end point (%)	95.8 (95.3-96.3)	87.2 (85.8-88.4)	96.2 (95.7-96.6)	89.8 (88.3-91.0)	96.2 (95.4-96.8)	91.2 (88.8-93.1)
HR (95% CI) for revision	3.19 (2.84-3.58), $p < 0.001$		2.58 (2.28-2.93), $p < 0.001$		1.96 (1.66-2.32), $p < 0.001$	
Survival rate (95% CI) with revision/reoperation† as end point (%)	86.4 (85.6-87.2)	77.5 (75.8-79.1)	87.2 (86.4-88.0)	81.2 (79.4-82.8)	88.3 (87.1-89.3)	83.1 (79.9-85.8)
HR (95% CI) for revision/reoperation	1.61 (1.50-1.73), $p < 0.001$		1.32 (1.22-1.43), $p < 0.001$		1.10 (0.99-1.22), $p = 0.086$	

*As defined by the National Joint Registry. †As determined with HES data.

UKR or TKR survival was calculated per surgeon per year and expressed as revisions per 100 implant-years⁹. A Kaplan-Meier estimate was produced to compare implant survival among the case-volume groups. Survival analysis was censored at eight years; this reflects the small numbers included in the National Joint Registry during its early years. All values presented in this report relate to eight-year survival.

Analysis

For the descriptive analysis, the effect of caseload on the revision rate was characterized using scatterplots, and curves were fitted using locally-weighted scatterplot smoothing (LOWESS)²⁸. For clarity, the scatter points were suppressed in the plots presented. As these plots demonstrated a nonlinear effect of UKR caseload on implant survival, three linear splines were fitted, corresponding to roughly linear segments observed on the plots. Once the splines were fitted, survival rates in each segment were compared using Cox regression.

In the second analysis, cases were allocated to three groups corresponding to each spline section, representing low, medium, and high UKR usage. Patient characteristics in each group were compared using linear and logistic regression, and multivariable regression was undertaken to determine whether the differences in patient factors among the groups explained the difference in outcomes.

In the final analysis, the UKRs in each of the volume groups were compared with TKRs in matched patients. Both revisions and non-revision reoperations (such as manipulation under anesthesia for stiffness, arthroscopy, amputation, and arthrodesis) could be assessed using HES data, and both revision and revision/reoperation (which may be a better indicator of failure than revision alone) were used as end points in the survival analysis. Matching was performed using propensity score methods in order to adjust for baseline differences in patient characteristics and to address the issue of confounding by indication. Full details of the propensity score matching are given in the Appendix.

All statistical analyses were performed using Stata/IC (version 12 for Windows; StataCorp).

Source of Funding

This study was funded by Arthritis Research UK (grant number 20499) and the Royal College of Surgeons of England. Neither body was involved in the conduct of the study.

Results

Forty-nine percent (1272) of the 2589 surgeons listed in the National Joint Registry as performing a knee replacement had performed at least one UKR between 2004 and 2012 (Fig. 1). Users of UKR performed an average of 5.4 per year (standard deviation [SD] = 9.3), with 25% (313 of 1272) having a mean caseload of only one UKR per year in the years

that they performed UKR; this was the most common mean UKR caseload. As higher-volume surgeons perform more operations by definition, the mean number of cases per year on the patient level was higher (24.8 [SD = 25.0]). Increases in caseload were accompanied by an increase in the proportion of the surgeon's knee replacements that were UKRs (termed "usage" of UKR).

Ninety-eight percent (2536) of the 2589 surgeons had performed at least one TKR; the mean number of TKRs per year was 33.6 (SD = 32.5) on the surgeon level and 70.5 (SD = 49.6) on the patient level. Baseline patient characteristics are given in Table I.

Descriptive Analysis

Overall, the unadjusted eight-year implant survival rate was 97.1% (95% confidence interval [CI] = 97.0% to 97.2%) for TKR and 89.8% (95% CI = 89.1% to 90.4%) for UKR. For both operations, increasing caseload was associated with improving implant survival. However, this effect was much greater for UKR (Fig. 2). With UKR, there was an initial steep drop in the

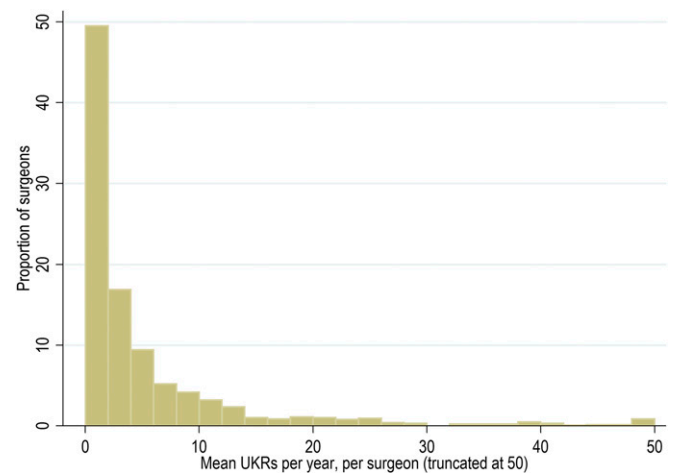


Fig. 1
Histogram demonstrating the distribution of UKR caseload among surgeons performing UKR in England and Wales.

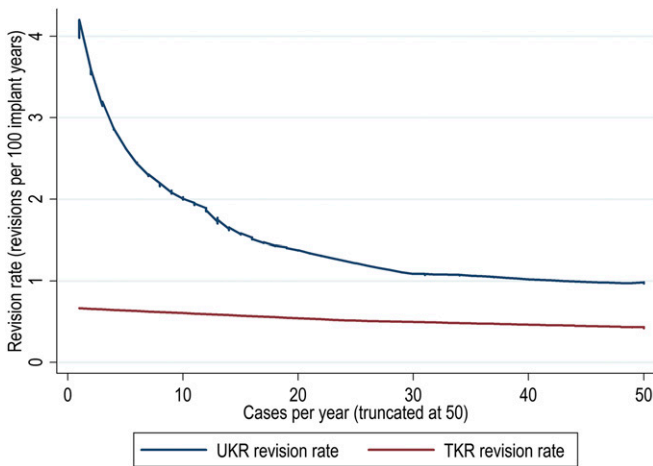


Fig. 2
LOWESS curve demonstrating the effect of increasing caseload on revision rates following UKR and TKR (up to fifty cases).

revision rate before the curve became shallower (at around ten cases per year); the revision rate plateaued at around thirty cases. For surgeons who performed fewer than ten cases per

year, the mean revision rate was 2.52 per 100 implant-years (an eight-year survival rate of 87.9% [95% CI = 86.9% to 88.8%]); this fell to 1.40 for surgeons who performed between ten and fewer than thirty cases per year (90.1% [95% CI = 89.0% to 91.2%]). With thirty cases or more per year, the revision rate was 0.98 (92.4% [95% CI = 90.9% to 93.6%]).

Linear splines were fitted, with knots placed at ten and thirty cases per year. The hazard ratio [HR] for revision was 0.86 (95% CI = 0.78 to 0.94) per five-case increase in annual caseload up to ten cases per year; 0.90 (95% CI = 0.86 to 0.93) between ten and thirty cases, and 1.00 (95% CI = 0.98 to 1.02) above thirty cases (Table II). With TKR, the effect of volume was effectively linear (Fig. 2). The HR for revision following TKR was 0.99 (95% CI = 0.98 to 0.99) for every five-case increase in annual caseload.

Patient Characteristics

Patient factors varied among the volume groups. Higher-volume surgeons operated on older patients, with more comorbidities but a lower level of deprivation (as measured with the Index of Multiple Deprivation [IMD], which is a U.K. governmental measure that assesses the level of deprivation in multiple domains [such as employment, income, and access to education] in

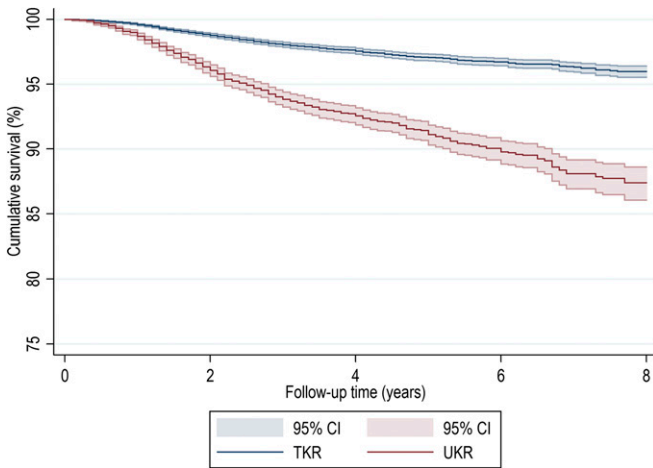


Fig. 3-A

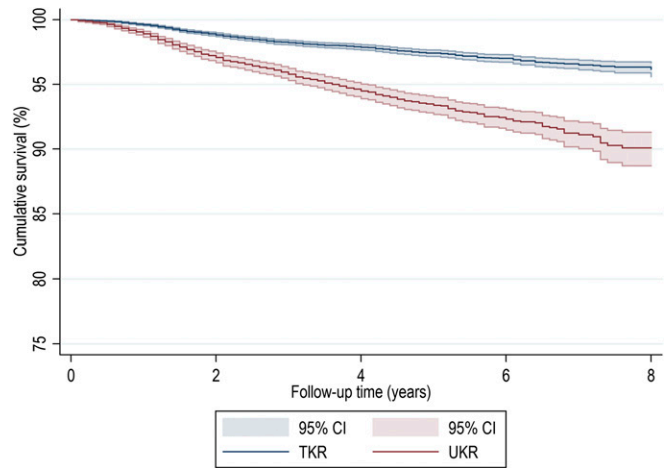


Fig. 3-B

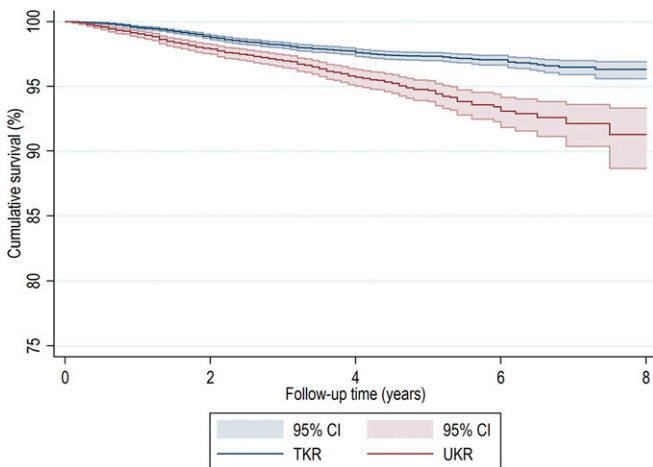


Fig. 3-C

Figs. 3-A, 3-B, and 3-C Matched survival comparisons, with revision (as defined by the National Joint Registry) as the end point, between the TKR group and the UKR low (Fig. 3-A), medium (Fig. 3-B), and high (Fig. 3-C)-volume groups. Additional details are given in Table IV.

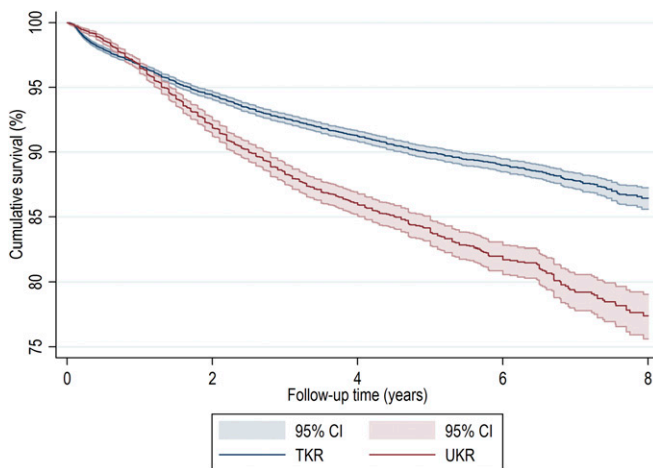


Fig. 3-D

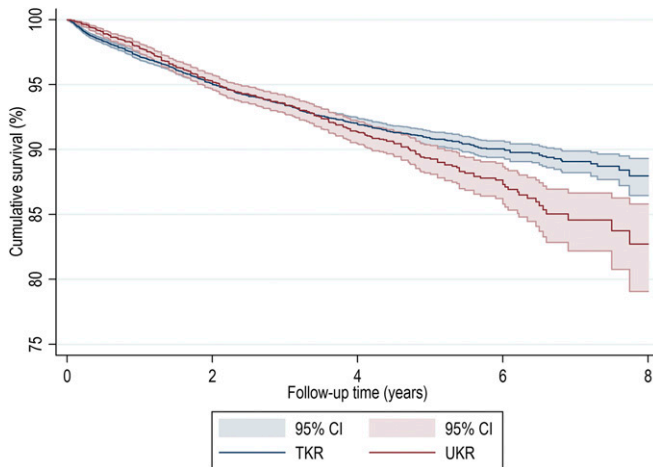


Fig. 3-F

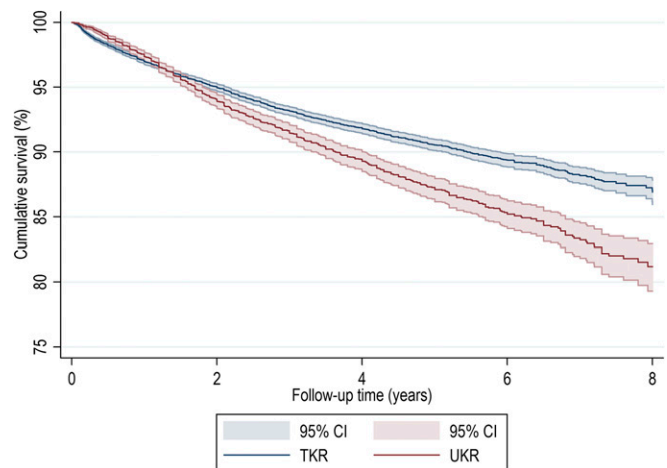


Fig. 3-E

Fig. 3-D, 3-E, and 3-F Matched survival comparisons, with revision/reoperation (as determined with the HES data) as the end point, between the TKR group and the UKR low (**Fig. 3-D**), medium (**Fig. 3-E**), and high (**Fig. 3-F**)-volume groups. Additional details are given in Table IV.

small geographical areas)²⁹. While these differences were significant, the magnitude of the differences among the patients operated on in the different case-volume groups was small. Details of the patient characteristics in each group are given in Table I.

Reasons for revision differed among the groups. Surgeons with lower annual caseloads of UKRs were more likely to revise for aseptic loosening, unexplained pain, or malalignment (Table III).

Comparison of Matched Patients

UKRs were matched to TKRs at a 1:3 ratio. More than 95% of the UKRs were matched. Marked differences in the HR for revision and reoperation were observed between groups. For revision (as defined by the National Joint Registry), the HR was reduced from 3.19 (95% CI = 2.84 to 3.58) in the low-volume group to 2.58 (95% CI = 2.28 to 2.93) in the medium-volume group and 1.96 (95% CI = 1.66 to 2.32) in the high-volume group. When both revisions and reoperations from the HES database were included, the HRs were reduced to 1.61 (95% CI = 1.50 to 1.73) in the low-volume group and 1.32 (95% CI = 1.22 to 1.43) in the medium-volume group. The revision/reoperation rate following UKR in the high-volume group was similar to that after TKR (HR = 1.10, 95% CI = 0.99 to 1.22).

Additional details are given in Table IV and Figures 3-A through 3-F.

Discussion

This study demonstrated an important effect of caseload on the revision rate following UKR, with a fourfold difference in revision rate between the lowest and highest-caseload surgeons. While there was a caseload effect in TKR, it was not as marked as it was in UKR. Part of this effect is likely to be due to patient selection: low-volume surgeons tended to operate on younger, healthier patients who may have had earlier-stage disease. The observed differences in patient characteristics were small and are unlikely to account for the whole effect observed. However, the fact that higher-volume surgeons offer UKR to a greater proportion of their patients seeking knee replacement (implying broader patient-selection criteria) suggests that there may be differences in patient selection aside from those that were measurable with use of the data available in the databases that we examined. Low-volume surgeons revise UKRs for different reasons than high-volume surgeons, with low-volume surgeons being more likely to revise for loosening, unexplained pain, or malalignment. This could be interpreted as indicating

a higher rate of technical errors (leading to the higher rate of revision for malalignment and loosening) or that low-volume surgeons are more likely to revise a UKR in the absence of a clear, correctable cause of symptoms (as evidenced by the higher rate of revision for unexplained pain)³⁰. Patients who underwent a UKR by a high-volume surgeon (who performed thirty or more cases per year) had medium-term survival rates (in terms of revision/reoperation) that were similar to those for matched patients who underwent TKR.

To facilitate the comparison of the low, medium, and high-caseload groups, we used cut-points selected on the basis of the data. Other approaches would be to designate a certain proportion of surgeons as “high-volume” as was done by Robertsson et al.²¹ (who so designated the top quarter of units) or introduce clinically plausible cut-points a priori, the approach taken by the New Zealand Joint Registry³¹ (surgeons performing more than one case per month being considered “high volume”) and by Baker et al.²⁰ (who considered 100 cases or more over seven years to represent a high volume). In fact, each method resulted in similar thresholds: our low-volume threshold was ten cases per year compared with twelve cases per year⁶ or around fourteen cases per year (assuming participation in all years of the registry)²⁰.


However, the caseload effect is continuous. Revision rates do not plateau until the caseload has reached thirty cases per year (restricting the analysis to a small number of surgeons). Attempts to produce thresholds on the basis of continuous predictors are difficult and of questionable value³². As such, our thresholds should not be taken to represent either minimum or optimum figures for UKR caseload. While all surgeons performing fewer than thirty UKRs per year may improve their implant survival rates by increasing their caseload, the smoothed scatterplots (Fig. 2) suggest that very-low-volume users (those performing fewer than five cases per year) are of the greatest concern as they attain the worst results. This group (comprising more than half of all UKR users) may need to modify their practice by adopting the practices, in terms of patient selection and surgical technique, of larger units that report good results³³. Better results can be obtained if, rather than many surgeons performing very few cases, fewer surgeons operate on larger numbers of patients each. Surgeons who wish to increase their caseload can do so by offering UKR to a greater proportion of their patients³⁴ or by becoming a referral practice. Surgeons who are unable to achieve a sufficient caseload should abandon UKR and refer suitable patients elsewhere.

While the observed differences between the results of high and low-volume surgeons are partly explained by the surgical and patient factors explored in this study, there remains a substantial residual difference in implant survival among the caseload groups not explained by these factors. Other factors are likely to include more subtle patient factors (such as stage of disease) and surgical technique. UKR is more straightforward to revise than TKR, and it is likely that surgeons’ thresholds for revising a poorly functioning UKR are lower than those for revising an equivalently poorly functioning TKR²⁴. It is not clear, on the basis of this data set, whether the effect on implant survival observed in the medium term (at eight years) is maintained over the long term.

Future studies of outcomes of UKR should include the effect of caseload on patient-reported outcomes together with more detailed study of patient selection and technique. The study of preoperative and postoperative radiographs is likely to be important in determining the effect of these variables. Longer-term studies will provide greater clarity as to how long the caseload effect endures.

In conclusion, this study has confirmed the importance of surgical caseload in determining the survival of UKRs and, to a lesser extent, TKRs. The reasons for this effect are complex and not fully explained by variables recorded in the National Joint Registry; however, the patient selection and revision threshold of lower-volume surgeons may be factors. Examination of matched patients in this study demonstrated that surgeons performing a high volume of UKRs can achieve revision/reoperation rates similar to those observed following TKR.

Appendix

 A detailed description of the propensity score matching is available with the online version of this article as a data supplement at jbjs.org. ■

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