BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2017-020977
Article Type:	Research
Date Submitted by the Author:	04-Dec-2017
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Primary Subject Heading:	Health economics
Secondary Subject Heading:	Surgery
Keywords:	Osteoarthritis, Unicompartmental knee replacement, Total knee replacement, Knee < ORTHOPAEDIC & TRAUMA SURGERY

Cost -effectiveness of unicompartmental compared to total knee replacement: a population-based study using data from the National Joint Registry for England and Wales

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KEYWORDS
Knee; Osteoarthritis; Arthroplasty; Unicompartmental knee replacement; Total knee replacement

ABSTRACT

Objectives

To assess the value for money of unicompartmental knee replacement (UKR) compared to total knee replacement (TKR).

Design

A lifetime Markov model provided the framework for the analysis.

Setting

Data from the National Joint Registry (NJR) for England and Wales primarily informed the analysis.

Participants

Propensity score matched patients in the NJR who received either a UKR or TKR.

Interventions

UKR is a less invasive alternative to TKR, where only the compartment affected by osteoarthritis is replaced.

Primary outcome measures

Incremental Quality-Adjusted Life Years (QALYs) and health system costs.

Results

The provision of UKR is expected to lead to a gain in QALYs compared to TKR for all age and gender subgroups (Male <60: 0.12, 60-75: 0.20, 75+: 0.19, Female <60: 0.10, 60-75: 0.28, 75+: 0.44) and a reduction in costs (Male <60: -£1,223, 60-75: -£1,355, 75+: -£2,005, Female <60: -£601, 60-75: -£935, 75+: -£1,102 per patient over the lifetime). UKR is expected to lead to a reduction in QALYs compared to TKR when performed by surgeons with low UKR utilisation, but an increase among those with high utilisation (<10%, median 6%: -0.04, ≥10%, median 27%: 0.26). Regardless of surgeon usage, costs associated with UKR are expected to be lower than those of TKR (<10%: -£127, ≥10%: -£758).

Conclusions

UKR can be expected to generate better health outcomes and lower lifetime costs than TKR. Surgeon usage of UKR does, though, have a significant impact on the cost-effectiveness of the procedure. To achieve the best results, surgeons need to perform a sufficient proportion of knee replacements as UKR, hence low-usage surgeon may need to broaden their indications of UKR to achieve this.

ARTICLE SUMMARY

Strengths and limitations of this study

- Routinely collected data provided real-world evidence of costs and health outcomes following UKR and TKR.
- Propensity score matching was used to identify comparable individuals who received UKR or TKR.
- Differences between comparator groups may have remained in unobserved characteristics, such as pre-operative radiographs.
- Assumptions were required to extrapolate quality of life and risk of revision over patient lifetimes.

INTRODUCTION

For individuals with end-stage symptomatic osteoarthritis of the knee, total knee replacement (TKR) relieves pain and improves function.[1] In a substantial proportion of cases, by some estimates up to 50%, patients could receive a unicompartmental knee replacement (UKR) instead. UKR is less invasive than TKR, sparing the normal joint surfaces and cruciate ligaments,[2, 3] and consequently is associated with a faster recovery and lower risk of post-operative complications and mortality.[4, 5] In early and late comparisons of patient-reported outcomes (PROMs), UKR has also been shown to result in superior outcomes overall, with a higher proportion of patients reporting an excellent result.[6, 7] However, UKR is also associated with a higher risk of revision than TKR,[4] with this due in large part to a lower threshold for revision.[8]

The choice between UKR and TKR also has economic implications. Given that the procedure is quicker and length of stay is reduced, undertaking a UKR can be expected to require fewer health system resources than a TKR. This upfront cost-saving could, however, be offset by the cost of additional reoperations and revisions. Differences in outcomes, in terms of pain and function, may also lead to differences in primary health care utilisation which would further affect the overall costs of the procedures.

The relative merit of each procedure can be expected to vary depending on patient and surgical factors. Outcomes following UKR, in particular, are impacted by surgical factors. Surgeons' caseload (the number of UKR performed) and usage of UKR (the percentage of their primary knee replacements that are UKRs) has been shown to have a substantial impact on the success of UKR with those performed by high usage surgeons expected to have comparable reoperation rates to TKR.[9]

Cost-effectiveness analyses offer a means of reducing decision uncertainty by providing a comparative analysis of both the costs and health outcomes of UKR and TKR. The aim of this study was to estimate the cost-effectiveness of UKR compared to TKR based on routinely-collected data from the UK and, in particular, to assess how cost-effectiveness varies depending on i) the age and gender of patients and ii) surgeon usage of UKR.

MATERIALS AND METHODS

Target population and subgroups

The study population for this analysis are those patients who could receive either a UKR or TKR. We use propensity score matching to identify those patients who received a TKR who were similar in all relevant observable characteristics to patients who received a UKR and assume both groups to be eligible for a UKR but ultimately receiving either a TKR or a UKR. We consider the cost-effectiveness of UKR compared to TKR in terms of six subgroups based on age (<60, 60 to 75, and >75) and gender. In a further analysis, we consider the effect of surgeon 'usage' of UKR on cost-effectiveness for two subgroups (<10 and ≥10%).

Decision model

A lifetime Markov model, shown in Figure 1, provides the framework for the analysis, with patients passing through clinically and economically important health states as time passes.[10] Patients begin by having a primary UKR or TKR, after which they have a revision operation or remain unrevised. After a revision, patients can have a further revision (re-revised) or remain 'revised'. Following a re-revision, patients remain as 're-revised' until death. From all health states patients have a risk of death and the model goes through consecutive cycles until all patients have died. Patients can transition between states on a yearly basis. The key simplifying assumptions of the model are that patients can have only two revisions and that only one revision can occur in a year. While

reoperations are not incorporated as a model state, their likelihood and costs are incorporated in the unrevised state.

Study perspective

This evaluation has been undertaken from a healthcare system perspective, hence only the costs incurred by the health system are included. These costs relate to surgical procedures being undertaken and primary care utilisation by patients. For health care interventions to be considered cost-effective (i.e. providing sufficient value for money to merit their provision) in the UK they should have an incremental cost per additional quality-adjusted life year (QALY) of less than £20,000 to £30,000.[11] For this analysis the cost-effectiveness of UKR is considered at the lower threshold of £20,000.

Measurement of effectiveness

An extract of data from the National Joint Registry (NJR) for England and Wales linked to the Hospital Episode Statistics (HES) database and the Office for National Statistics (ONS) informed estimates of the effectiveness of UKR and TKR. This data was previously used to compare adverse events following the procedures, with propensity scores used to match 25,334 UKRs to 75,996 comparable TKRs who received their primary procedure between 2003 and 2012.[9] These same matched patients were split into the age and gender subgroups for this analysis. As surgeon usage of UKR was not a variable in the original propensity score matching, matching was re-run to achieve balance within usage subgroups (see Appendix). This ensured that the comparator groups, UKR performed by surgeons with usage under 10% against TKR, and UKR by surgeons with usage equal to or over 10% against TKR, were balanced in their observable characteristics.

Parametric models were specified independently for each treatment subgroup to estimate the risk of revision and death. For the base case analysis, the Weibull distribution was used for both. The risk of revision was extrapolated using estimates from the models, and risk of death was assumed to return to that given by age- and gender-specific UK life tables after the period of follow up.[12] Sensitivity analyses were performed for the risk of revision with the analysis re-run using the log-normal and exponential distributions instead of the Weibull. Further details of the estimated parametric models are provided in the Appendix.

Risk of re-revision was based on evidence from the NJR which reported that in the first year following a revision patients have a 2.7% probability of a re-revision, and a 1.4% chance in subsequent years.[13] With risk of re-revision being similar following a revision of UKR and TKR,[14] these risks were applied in the same manner for both procedures. Risk of mortality following a revision and re-revision was assumed to be equal to that of those unrevised.

Estimating resource use and costs

The hospital costs associated with the primary procedures and revisions were based on patients' Healthcare Resource Group (HRG) codes (which classify episodes with similar levels of resource consumption into the same group) and length of stay, with costs estimated using the 2014/15 National Tariff Payment System.[15] In addition, the costs of any implant-retaining reoperations over the five years following each surgery were also incorporated. The cost of a re-revision was assumed to be the same as a revision in the base case analysis. The effect of this assumption on the results was tested by re-running the analysis with a re-revision expected to have a cost 50% higher than that of a revision.

For primary care costs an extract of the Clinical Practice Research Datalink (CPRD) was used where 335 UKRs were matched with 1,005 TKRs based on propensity scores. These patients and their costs

are summarised in the Appendix. The choice of procedure was found to have no significant effect on resource use and so the costs of treatment groups were pooled and single estimates extracted for each age and gender subgroup.

Future costs and health outcomes were discounted by an annual rate of 3.5%, in line with guidelines for England and Wales.[16] Costs are in British pounds, in 2014 prices. Estimated hospital and primary care costs are detailed in the Appendix.

Measurement and valuation of preference-based outcomes

As patient-reported outcome measures (PROMs) have only been collected since 2009, a separate propensity score matched cohort of 3,519 UKRs and 10,557 TKRs for whom these data were available were used to inform estimates of health-related quality of life for each subgroup considered. Again, these patients and the process of matching have been previously described in detail,[6] and matching was re-run for usage subgroups (see Appendix).

In the year following a primary, patients were expected to steadily progress from their pre-operative score to their post-operative score at six months, at which they would remain for the rest of year. As EQ-5D following UKR and TKR remains stable over ten years following surgery for those who remain unrevised,[7] in the absence of any further procedure those unrevised were expected to remain at their post-operative score. A similar approach was used for revision, with patients expected to progress from their pre-operative score to their post-operative score over six months, at which point they were expected to remain unless they went on to have a re-revision. However, due to the small number of individuals with a revision and scores available, subgroups were pooled for revision parameters. Quality-of-life for a re-revision was assumed to fall in the same proportion as they did from primary to a revision procedure. To test the impact of this assumption, a sensitivity analysis was conducted where the quality of life for a re-revision was assumed instead to remain equal to that of revision. Estimates of health-related quality-of-life were based on EQ-5D collected prior to and six-month following surgery (see Appendix).

Analytic methods

Expected (mean) costs and QALYs were estimated for each subgroup receiving either UKR or TKR. The effect of parameter uncertainty was assessed using probabilistic sensitivity analysis, with input parameters assigned from probability distributions and 1,000 Monte Carlo simulations conducted for each subgroup. Probability distributions were based on the type of data, with gamma distributions used for costs as well as pre-operative quality of life so as to allow values below zero, beta distributions used for post-operative quality of life, and normal distributions used for the coefficients of parametric models and age.[17, 18] The sets of estimated costs and QALYs from each of 1,000 Monte Carlo simulations are presented, alongside the expected results, on a cost-effectiveness plane.

RESULTS

Compared to TKR, UKR was found to be associated with a greater likelihood of revision over individuals remaining lifetimes for each of the subgroups. UKR though was associated with better post-operative quality of life following the primary procedure that TKR for all age and gender subgroups, with the difference most pronounced for older patients. Moreover, those undergoing revision following UKR had better quality of life prior to and following revision than those who had TKR. For all subgroups, the hospital costs of primary and revision surgery were lower for UKR than TKR. See Appendix for further details.

UKR was found to be cost-saving and health improving compared to TKR for all age and gender subgroups, making UKR the 'dominant' treatment choice for those individuals eligible for either

procedure (see Table 1). The largest expected savings were for males over 75 while the biggest improvement in quality of life was for females over 75. For those aged over 60 years of age, parameter uncertainty had little effect on the conclusion that UKR was cost-effective. However, for those under 60 there was some uncertainty, with a 13% and 28% probability that TKR was cost-effective for males and females under 60, respectively. Figure 2 presents the estimated mean and probabilistic sets of incremental costs and QALYs associated with the provision of UKR rather than TKR for each age and gender subgroup. These findings were broadly robust to changes in modelling assumptions (see Table 2 and Appendix for full results from each scenario analysis).

When UKR was performed by surgeons with a usage of the procedure equal to or above 10% (median usage of 27%), UKR was found to be unequivocally cost-saving and health improving compared to TKR, as shown in Table 3. When performed by surgeons with a usage of less than 10% (median usage of 6%), however, UKR no longer led to better health outcomes than TKR and TKR was the cost-effective procedure. Figure 3 presents the estimated means and sets of costs and QALYs for both usage subgroups.

DISCUSSION

Principal findings

For patients who are eligible for either procedure, the provision of UKR rather than TKR has been estimated to lead to a gain in QALYs and a reduction in costs for all age and gender subgroups. There is little uncertainty around this conclusion for older patients. Such patients have, given their lower life expectancy, a lower lifetime risk of revision and report greater improvements in post-operative quality of life compared to TKR than younger patients. Significant uncertainty does surround whether UKR would be health-improving for younger patients for whom even relatively small differences in annual revision rates lead to substantial differences in lifetime revision rates.

Surgeon usage of UKR, the percentage of the knee replacements they perform that were UKRs, had a significant impact on the cost-effectiveness of the procedure. UKR was expected to be cost-effective when compared to TKR with 100% probability (given parameter uncertainty) when performed by surgeons with usage at or above 10%, with these surgeons having a median usage of 27%. However, when UKR performed by low usage surgeons were compared against TKR, TKR was the cost-effective option.

Limitations of the study

This analysis was based on routinely-collected data from the NHS in England and Wales. While this dataset has the advantage of providing real-world evidence for costs and health outcomes following UKR and TKR, it also has the potential pitfalls of any such observational data. In particular, confounding by indication can be expected with treatment selection based on patient and surgical characteristics. Propensity score matching was used to achieve balance in a wide range of observed characteristics, however imbalances may still exist in unobserved factors which could bias the findings of the study.

With costs and health outcomes estimated over the remaining lifetimes of patients, modelling assumptions were unavoidable. Individuals' risk of revision over their remaining lifetimes were based on observed revisions over the eight years following surgery. In addition, quality of life was based on scores recorded prior to and six month following primary and revision procedures and, based on previous research,[7] it was assumed that individuals would remain at their post-operative scores following both a primary and a revision in this analysis. Furthermore, quality of life associated with re-revision was assumed to have dropped by the same proportion as that observed from primary to revision and the cost of a re-revision was assumed to be equivalent to that of a revision.

These assumptions were necessarily subjective; however, scenario analyses showed the findings of the study to be robust to changes in these assumptions.

Study findings in context

In line with findings from previous economic evaluations of UKR and TKR,[19] in this study we found UKR to be less costly than TKR.[7] Furthermore, consistent with previous research, UKR was also found to lead to better health outcomes for patients aged 65 and over. Little uncertainty surrounds this conclusion for older patients, who benefit most from a less-invasive procedure and have a low lifetime risk of revision. For younger patients, where findings regarding health outcomes are mixed,[20-22] this analysis found that UKR was also expected to lead to better health outcomes than TKR, although there was significant uncertainty in this conclusion. The variation in findings for younger patients across studies appears to be driven by differences in estimates for both the risk of revision and the expected effect of revision on quality of life.[7]

This study has also highlighted the importance of surgeon usage of UKR on the cost-effectiveness of the procedure. In the high usage group, with a median usage of 27%, UKR was found, with no parameter uncertainly, to lead to better health outcomes and cost-savings compared to TKR. In contrast, in the low usage group UKR provided worse health outcomes and only small cost savings. The poor results of those with low usage are likely to be due to both less experience with the procedure and inappropriate patient selection. High usage surgeons, therefore, should be supported while low usage surgeons should consider changing their practice. If surgeons with low or no usage of UKR learnt and applied the indications and techniques of current high usage surgeons, they can be expected to achieve similar results.

CONCLUSIONS

For those patients with appropriate indications, UKR provides an alternative to TKR which is less costly for the health system to provide and leads to overall lifetime health outcomes. If surgeons performing UKR achieved sufficient usage of the procedure, future economic and population health gains would likely be increased even further. Additional work is needed to identify the optimal usage of UKR, which may depend on the type of implants used. Surgeons should not have a low usage and be performing UKR in less than 10% of their knee replacements. The median usage in the high usage group was 27% so it would be reasonable for surgeons to aim for a quarter of their knee replacements to be UKR. However it has been shown that up to 50% of replacements could be UKR, so the optimal usage may be higher.[23]

ACKNOWLEDGMENTS

We thank the patients and staff of all the hospitals in England and Wales who have contributed data to the National Joint Registry; and the Healthcare Quality Improvement Partnership (HQIP), the NJR Steering Committee, and staff at the NJR Centre for facilitating this work. The authors have conformed to the NJR's standard protocol for data access and publication. The views expressed represent those of the authors and do not necessarily reflect those of the National Joint Registry Steering Committee or the Healthcare Quality Improvement Partnership (HQIP) who do not vouch for how the information is presented.

FUNDING

This research was supported by funding from Zimmer Biomet. Zimmer Biomet had no other role in the design or conduct of the study.

CONTRIBUTORS

EB, ADL, TWH, AJ, HGP, DWM and RPV all made substantial contributions to conception and design of the study. EB, ADL and RPV undertook the statistical analysis. EB, DWM and RPV drafted the manuscript with ADL, TWH, AJ and HGP revising it for important intellectual content. All authors read and approved the final manuscript.

COMPETING INTERESTS

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: financial support for the submitted work from Zimmer Biomet; HGP and DWM have received consultancy fees and DWM has received royalties from Zimmer Biomet; TWH and DWM hold various patents related to Total and Unicompartmental Knee Replacement.

ETHICAL APPROVAL

Not required.

DATA SHARING

Access to data is available from the National Joint Registry for England and Wales.

REFERENCES

1. Carr AJ, Robertsson O, Graves S, Price AJ, Arden NK, Judge A, et al. Knee replacement. The Lancet. 2012;379(9823):1331-40.
2. Ashraf ST, Ackroyd CE, Newman JH. Compartmental knee arthroplasty. Current Orthopaedics. 2003;17(2):134-43.
3. Lutzner J, Kasten P, Gunther KP, Kirschner S. Surgical options for patients with osteoarthritis of the knee. Nat Rev Rheumatol. 2009 Jun;5(6):309-16.
4. Liddle AD, Judge A, Pandit H, Murray DW. 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. The Lancet. 2014;384(9952):1437-45.
5. Hunt LP, Ben-Shlomo Y, Clark EM, Dieppe P, Judge A, MacGregor AJ, et al. 45-day mortality after 467 779 knee replacements for osteoarthritis from the National Joint Registry for England and Wales: an observational study. The Lancet. 2014;384(9952):1429-36.
6. Liddle AD, Pandit H, Judge A, Murray DW. Patient-reported outcomes after total and unicompartmental knee arthroplasty: a study of 14,076 matched patients from the National Joint Registry for England and Wales. Bone Joint J. 2015 Jun;97-B(6):793-801.
7. Burn E, Sanchez-Santos MT, Pandit HG, Hamilton TW, Liddle AD, Murray DW, et al. Ten-year patient-reported outcomes following total and minimally invasive unicompartmental knee arthroplasty: a propensity score-matched cohort analysis. Knee Surg Sports Traumatol Arthrosc. 2016 Dec 29.
8. Goodfellow JW, O'Connor JJ, Murray DW. A critique of revision rate as an outcome measure: re-interpretation of knee joint registry data. J Bone Joint Surg Br. 2010 Dec;92(12):1628-31.
9. Liddle AD, Pandit H, Judge A, Murray DW. Optimal usage of unicompartmental knee arthroplasty: a study of 41 986 cases from the National Joint Registry for England and Wales. Bone Joint J. 2015 Nov;97-B(11):1506-11.
10. Briggs A, Sculpher M. An introduction to Markov modelling for economic evaluation. Pharmacoeconomics. 1998 Apr;13(4):397-409.
11. McCabe C, Claxton K, Culyer AJ. The NICE cost-effectiveness threshold - What it is and what that means. Pharmacoeconomics. 2008;26(9):733-44.
12. National Life Tables: United Kingdom [database on the Internet]. 2016.
13. National Joint Registry for England W, Northern Ireland and the Isle of Man. 13th annual report. 2016.
14. Leta TH, Lygre SH, Skredderstuen A, Hallan G, Gjertsen JE, Rokne B, et al. Outcomes of Unicompartmental Knee Arthroplasty After Aseptic Revision to Total Knee Arthroplasty: A Comparative Study of 768 TKAs and 578 UKAs Revised to TKAs from the Norwegian Arthroplasty Register (1994 to 2011). The Journal of bone and joint surgery American volume. 2016 Mar 16;98(6):431-40.
15. National tariff payment system 2014/15 [database on the Internet]. 2013.
16. NICE. Guide to the methods of technology appraisal 2013. 2013.
17. Briggs A, Sculpher M, Claxton K. Decision Modelling for Health Economic Evaluation: Oxford University Press; 2006.
18. Edlin R, McCabe C, Hulme C, Hall P, Wright J. Cost effectiveness modelling for health technology assessment. A practical course: Adis; 2015.
19. Burn E, Liddle AD, Hamilton TW, Pai S, Pandit HG, Murray DW, et al. Choosing Between Unicompartmental and Total Knee Replacement: What Can Economic Evaluations Tell Us? A Systematic Review. PharmacoEconomics - Open. 2017.
20. Peersman G, Jak W, Vandenlangenbergh T, Jans C, Cartier P, Fennema P. Cost-effectiveness of unicondylar versus total knee arthroplasty: a Markov model analysis. The Knee. 2014;21:S37-S42.
21. Konopka JF, Gomoll AH, Thornhill TS, Katz JN, Losina E. The cost-effectiveness of surgical treatment of medial unicompartmental knee osteoarthritis in younger patients: a computer model-

based evaluation. The Journal of bone and joint surgery American volume. 2015 May 20;97(10):807-17.

22. Ghomrawi HM, Eggman AA, Pearle AD. Effect of age on cost-effectiveness of unicompartmental knee arthroplasty compared with total knee arthroplasty in the U.S. The Journal of bone and joint surgery American volume. 2015 Mar 4;97(5):396-402.

23. Willis-Owen CA, Brust K, Alsop H, Miraldo M, Cobb JP. Unicondylar knee arthroplasty in the UK National Health Service: an analysis of candidacy, outcome and cost efficacy. The Knee. 2009 Dec;16(6):473-8.

TABLE 1: BASE CASE COST-EFFECTIVENESS RESULTS FOR AGE AND GENDER SUBGROUPS

	TKR		UKR				
	QALYs	Costs	QALYs	Costs	Δ QALYs	Δ Costs	ICER (probability cost-effective*)
Male, <60	10.28 (10.07 to 10.47)	15,357 (14,704 to 16,019)	10.39 (10.11 to 10.70)	14,134 (13,489 to 14,810)	0.12 (-0.19 to 0.47)	-1,223 (-1,439 to -1,014)	UKR dominant (87%)
Male, 60-75	8.61 (8.50 to 8.70)	13,307 (12,584 to 14,037)	8.81 (8.63 to 8.97)	11,952 (11,246 to 12,704)	0.20 (0.01 to 0.39)	-1,355 (-1,610 to -1,122)	UKR dominant (100%)
Male, 75+	5.61 (5.49 to 5.73)	11,454 (10,506 to 12,511)	5.80 (5.64 to 5.97)	9,450 (8,442 to 10,631)	0.19 (0.02 to 0.37)	-2,005 (-2,361 to -1,521)	UKR dominant (100%)
Female, <60	10.68 (10.50 to 10.89)	16,961 (16,101 to 17,899)	10.78 (10.42 to 11.09)	16,360 (15,514 to 17,273)	0.10 (-0.33 to 0.47)	-601 (-887 to -350)	UKR dominant (72%)
Female, 60-75	8.96 (8.84 to 9.06)	13,814 (13,089 to 14,602)	9.24 (9.04 to 9.43)	12,878 (12,068 to 13,702)	0.28 (0.05 to 0.50)	-935 (-1,186 to -710)	UKR dominant (100%)
Female, 75+	6.02 (5.82 to 6.15)	11,410 (10,541 to 12,378)	6.46 (6.20 to 6.69)	10,308 (9,312 to 11,378)	0.44 (0.18 to 0.71)	-1,102 (-1,646 to -695)	UKR dominant (100%)

Expected (mean) values with 95% confidence intervals in parentheses. UKR is considered 'dominant' if it is expected to improve health outcomes and reduce health care costs. *Given a cost-effectiveness threshold of £20,000.

TABLE 2: SCENARIO ANALYSES

	Age and gender subgroups					
	Male, <60	**Male, 60-75**	**Male, 75+**	**Female, <60**	**Female, 60-75**	**Female, 75+**
Base case assumptions	UKR dominant (87%)	UKR dominant (100%)	UKR dominant (100%)	UKR dominant (72%)	UKR dominant (100%)	UKR dominant (100%)
Distribution of parametric model for revision risk						
Exponential	UKR dominant (92%)	UKR dominant (100%)	UKR dominant (100%)	UKR dominant (78%)	UKR dominant (100%)	UKR dominant (100%)
Log-normal	UKR dominant (89%)	UKR dominant (100%)	UKR dominant (100%)	UKR dominant (77%)	UKR dominant (100%)	UKR dominant (100%)
Health utility						
Re-revision equal to revision	UKR dominant (95%)	UKR dominant (100%)	UKR dominant (100%)	UKR dominant (91%)	UKR dominant (100%)	UKR dominant (100%)
Cost						
Cost of re-revision 50% higher than revision	UKR dominant (83%)	UKR dominant (100%)	UKR dominant (100%)	UKR dominant (73%)	UKR dominant (100%)	UKR dominant (100%)

ICER with probability of being cost-effective, based on probabilistic sensitivity analysis and given a cost-effectiveness threshold of £20,000, in parentheses. UKR is considered 'dominant' if it is expected to improve health outcomes and reduce health care costs. Full results for each scenario analysis are detailed in the Appendix.

TABLE 3: BASE CASE COST-EFFECTIVENESS RESULTS FOR USAGE OF UKR SUBGROUPS

	TKR		UKR				
	QALYs	Costs	QALYs	Costs	Δ QALYs	Δ Costs	ICER (probability cost-effective*)
UKR <10%	8.67 (8.53 to 8.80)	13,267 (12,834 to 13,731)	8.62 (8.38 to 8.84)	13,140 (12,643 to 13,614)	-0.04 (-0.32 to 0.21)	-127 (-429 to 127)	3,000 (37%)
UKR ≥10%	8.81 (8.73 to 8.88)	13,170 (12,726 to 13,614)	9.06 (8.94 to 9.18)	12,411 (11,978 to 12,856)	0.26 (0.12 to 0.40)	-758 (-939 to -579)	UKR dominant (100%)

Expected (mean) values with 95% confidence intervals in parentheses. UKR is considered 'dominant' if it is expected to improve health outcomes and reduce health care costs. *Given a cost-effectiveness threshold of £20,000.

Figure 1: Model outline. The decision-analytic model provides the framework for the analysis.

Figure 2: Cost-effectiveness plane for age and gender subgroups. The sets of estimated incremental costs and QALYs associated with the provision of UKR rather than TKR from each of the Monte Carlo simulations are shown as points with the expected results as triangles.

Figure 3: Cost-effectiveness plane for usage subgroups. The sets of estimated incremental costs and QALYs associated with the provision of UKR rather than TKR from each of the Monte Carlo simulations are shown as points with the expected results as triangles.

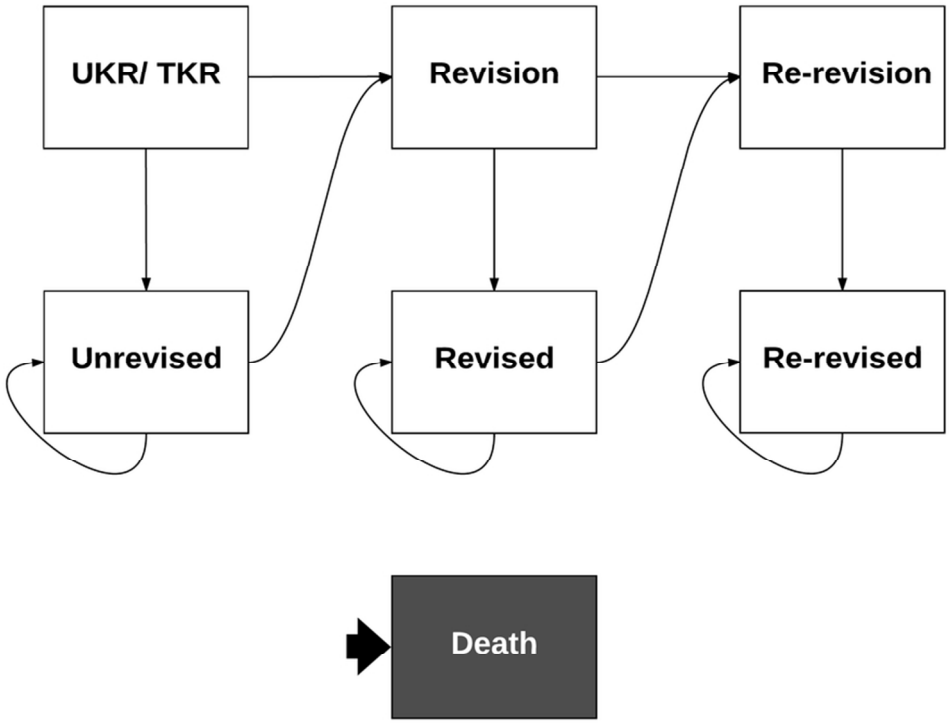

Figure 1: Model outline. The decision-analytic model provides the framework for the analysis.

39x30mm (600 x 600 DPI)

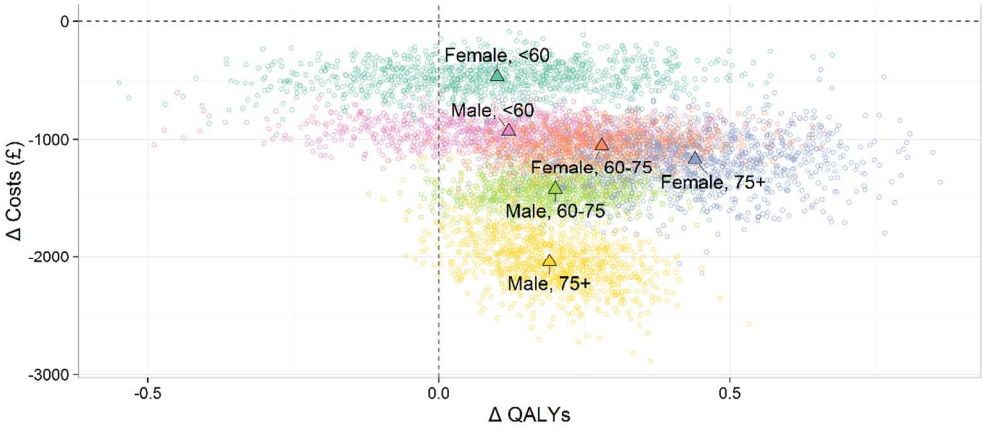

Figure 2: Cost-effectiveness plane for age and gender subgroups. The sets of estimated incremental costs and QALYs associated with the provision of UKR rather than TKR from each of the Monte Carlo simulations are shown as points with the expected results as triangles.

159x70mm (220 x 220 DPI)

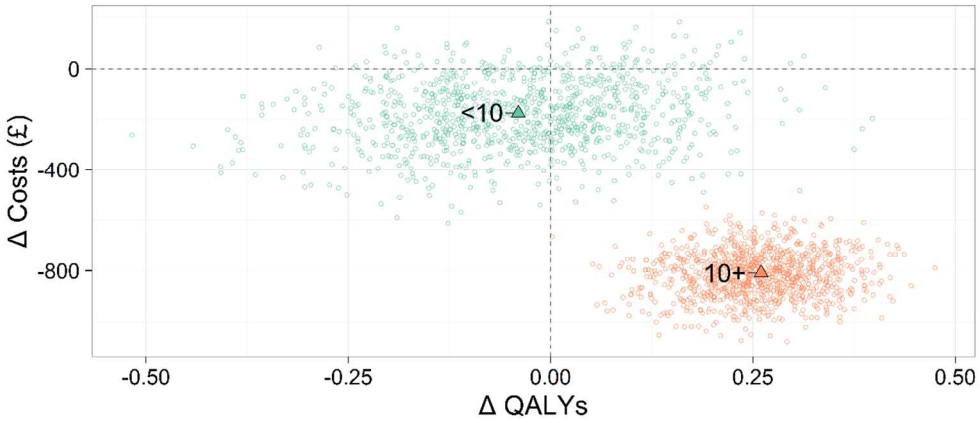

Figure 3: Cost-effectiveness plane for usage subgroups. The sets of estimated incremental costs and QALYs associated with the provision of UKR rather than TKR from each of the Monte Carlo simulations are shown as points with the expected results as triangles.

159x70mm (220 x 220 DPI)

APPENDIX

PATIENT COUNTS FOR EACH SUBGROUP

Table A1.1: Patient counts for each subgroup

	NJR-HES		HES-PROMs		CPRD
	TKR	UKR	TKR	UKR	All
Age and gender subgroups					
Male, <60	11156	3677	1487	473	82
Male, 60-75	11616	4268	3456	1155	175
Male, 75+	22979	7468	641	241	57
Female, <60	19320	6118	1613	592	54
Female, 60-75	5305	1914	2850	882	164
Female, 75+	5371	1805	510	176	62
Usage subgroups					
UKR <10%	13690	4564	2052	684	-
UKR 10+%	60544	20682	8379	2793	-

NJR linked to HES was used to estimate initial transition probabilities and hospital costs. HES-PROMs was used to estimate quality of life following primary procedure. CPRD was used to estimate primary care costs.

PROPENSITY SCORE MATCHING FOR USAGE SUBGROUPS

Table A2.1 Patient characteristics before and after matching low usage UKRs (<10%) with TKRs for transition probabilities and hospital costs

	Before matching			After matching		
	TKR	UKR (usage <10%)	SMD	TKR	UKR (usage <10%)	SMD
Number of patients	75753	4564		13690	4564	
Age at surgery (mean (sd))	64.72 (9.30)	62.42 (9.11)	0.25	62.54 (9.40)	62.42 (9.11)	0.014
Unit type (%)			0.133			0.001
Public hospital	63990 (84.5)	4011 (87.9)		12030 (87.9)	4011 (87.9)	
Independent hospital	9098 (12.0)	480 (10.5)		1443 (10.5)	480 (10.5)	
Independent sector treatment centre	2665 (3.5)	73 (1.6)		217 (1.6)	73 (1.6)	
Thromboprophylaxis						
Drugs (%)			0.081			0.013
Aspirin	9498 (12.5)	487 (10.7)		1472 (10.8)	487 (10.7)	
Direct thrombin inhibitor	2622 (3.5)	161 (3.5)		458 (3.3)	161 (3.5)	
Unfractionated or low molecular weight heparin	397 (0.5)	21 (0.5)		59 (0.4)	21 (0.5)	
None/Unspecified	9325 (12.3)	606 (13.3)		1847 (13.5)	606 (13.3)	
Other	53187 (70.2)	3265 (71.5)		9786 (71.5)	3265 (71.5)	
Warfarin	724 (1.0)	24 (0.5)		68 (0.5)	24 (0.5)	
Mechanical (%)			0.053			0.022
None/Unspecified	9034 (11.9)	604 (13.2)		1767 (12.9)	604 (13.2)	
Foot pumps	7474 (9.9)	458 (10.0)		1359 (9.9)	458 (10.0)	
Intermittent calf compression	9166 (12.1)	508 (11.1)		1465 (10.7)	508 (11.1)	
Thromboembolic deterrent stockings	49069 (64.8)	2920 (64.0)		8856 (64.7)	2920 (64.0)	
Other	1010 (1.3)	74 (1.6)		243 (1.8)	74 (1.6)	
Gender (%)			0.017			0.016
M	39440 (52.1)	2403 (52.7)		7318 (53.5)	2403 (52.7)	
American Society of Anesthesiologists score (%)			0.104			0.024
1	16018 (21.1)	1152 (25.2)		3568 (26.1)	1152 (25.2)	
2	53087 (70.1)	3077 (67.4)		9181 (67.1)	3077 (67.4)	

3+	6648 (8.8)	335 (7.3)		941 (6.9)	335 (7.3)	
Comorbidities (Charlson index) (%)			0.028			0.009
None	60768 (80.2)	3681 (80.7)		11013 (80.4)	3681 (80.7)	
Mild	12511 (16.5)	755 (16.5)		2303 (16.8)	755 (16.5)	
Moderate	1967 (2.6)	99 (2.2)		291 (2.1)	99 (2.2)	
Severe	507 (0.7)	29 (0.6)		83 (0.6)	29 (0.6)	
Hypertension (mean (sd))	0.35 (0.48)	0.31 (0.46)	0.084	0.30 (0.46)	0.31 (0.46)	0.014
Ethnicity (%)			0.083			0.034
Undefined	9958 (13.1)	640 (14.0)		1933 (14.1)	640 (14.0)	
British (White)	61524 (81.2)	3661 (80.2)		10946 (80.0)	3661 (80.2)	
Irish (White)	411 (0.5)	32 (0.7)		103 (0.8)	32 (0.7)	
Any other White background	1401 (1.8)	101 (2.2)		323 (2.4)	101 (2.2)	
White and Black Caribbean (Mixed)	29 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
White and Black African (Mixed)	11 (0.0)	1 (0.0)		4 (0.0)	1 (0.0)	
White and Asian (Mixed)	42 (0.1)	7 (0.2)		14 (0.1)	7 (0.2)	
Any other Mixed background	31 (0.0)	1 (0.0)		7 (0.1)	1 (0.0)	
Indian (Asian or Asian British)	1068 (1.4)	47 (1.0)		151 (1.1)	47 (1.0)	
Pakistani (Asian or Asian British)	351 (0.5)	11 (0.2)		32 (0.2)	11 (0.2)	
Bangladeshi (Asian or Asian British)	26 (0.0)	1 (0.0)		3 (0.0)	1 (0.0)	
Any other Asian background	195 (0.3)	12 (0.3)		33 (0.2)	12 (0.3)	
Caribbean (Black or Black British)	259 (0.3)	17 (0.4)		54 (0.4)	17 (0.4)	
African (Black or Black British)	146 (0.2)	11 (0.2)		31 (0.2)	11 (0.2)	
Any other Black background	64 (0.1)	4 (0.1)		15 (0.1)	4 (0.1)	
Chinese (other ethnic group)	25 (0.0)	4 (0.1)		6 (0.0)	4 (0.1)	
Any other ethnic group	212 (0.3)	14 (0.3)		35 (0.3)	14 (0.3)	
IMD decile (mean (sd))	6.25 (2.67)	6.08 (2.71)	0.062	6.12 (2.70)	6.08 (2.71)	0.015
Fixation (%)			0.135			0.014
Cementless	5677 (7.5)	200 (4.4)		636 (4.6)	200 (4.4)	
Cemented	68544 (90.5)	4287 (93.9)		12814 (93.6)	4287 (93.9)	
Hybrid	1532 (2.0)	77 (1.7)		240 (1.8)	77 (1.7)	
Cases per consultant per year (mean (sd))	84.74 (58.78)	82.14 (56.83)	0.045	81.49 (56.53)	82.14 (56.83)	0.012

Table A2.2 Patient characteristics before and after matching low usage UKRs (<10%) with TKRs for quality of life

	Before matching			After matching		
	TKR	UKR (usage <10%)	SMD	TKR	UKR (usage <10%)	SMD
Number of patients	10441	684		2052	684	
Age at surgery (mean (sd))	64.38 (8.60)	61.96 (8.58)	0.281	62.19 (8.68)	61.96 (8.58)	0.027
Unit type (%)			0.108			0.006
Public hospital	7726 (74.0)	535 (78.2)		1601 (78.0)	535 (78.2)	
Independent hospital	2267 (21.7)	129 (18.9)		389 (19.0)	129 (18.9)	
Independent sector treatment centre	448 (4.3)	20 (2.9)		62 (3.0)	20 (2.9)	
Thromboprophylaxis						
Drugs (%)			0.029			0.028
Aspirin	2065 (19.8)	134 (19.6)		421 (20.5)	134 (19.6)	
Unfractionated or low molecular weight heparin	203 (1.9)	11 (1.6)		30 (1.5)	11 (1.6)	
None/Unspecified	2171 (20.8)	144 (21.1)		419 (20.4)	144 (21.1)	
Other	5908 (56.6)	388 (56.7)		1162 (56.6)	388 (56.7)	
Warfarin	94 (0.9)	7 (1.0)		20 (1.0)	7 (1.0)	
Mechanical (%)			0.091			0.024
None/Unspecified	2428 (23.3)	151 (22.1)		451 (22.0)	151 (22.1)	
Foot Pumps	887 (8.5)	69 (10.1)		213 (10.4)	69 (10.1)	
Intermittent calf compression	845 (8.1)	43 (6.3)		118 (5.8)	43 (6.3)	
Thromboembolic deterrent stockings	6154 (58.9)	412 (60.2)		1242 (60.5)	412 (60.2)	
Other	127 (1.2)	9 (1.3)		28 (1.4)	9 (1.3)	
Gender (%)			0.021			0.007
M	5511 (52.8)	354 (51.8)		1055 (51.4)	354 (51.8)	
American Society of Anesthesiologists score (%)			0.083			0.065
1	2183 (20.9)	154 (22.5)		431 (21.0)	154 (22.5)	

2	7585 (72.6)	474 (69.3)		1479 (72.1)	474 (69.3)	
3+	673 (6.4)	56 (8.2)		142 (6.9)	56 (8.2)	
Comorbidities (Charlson index) (%)			0.054			0.026
None	8622 (82.6)	564 (82.5)		1685 (82.1)	564 (82.5)	
Mild	1496 (14.3)	103 (15.1)		313 (15.3)	103 (15.1)	
Moderate	240 (2.3)	11 (1.6)		31 (1.5)	11 (1.6)	
Severe	83 (0.8)	6 (0.9)		23 (1.1)	6 (0.9)	
Hypertension (mean (sd))	0.35 (0.48)	0.36 (0.48)	0.025	0.35 (0.48)	0.36 (0.48)	0.017
Ethnicity (%)			0.099			0.073
Undefined	2253 (21.6)	148 (21.6)		470 (22.9)	148 (21.6)	
British (White)	7643 (73.2)	505 (73.8)		1494 (72.8)	505 (73.8)	
Irish (White)	52 (0.5)	4 (0.6)		15 (0.7)	4 (0.6)	
Any other White background	225 (2.2)	14 (2.0)		43 (2.1)	14 (2.0)	
White and Black Caribbean (Mixed)	7 (0.1)	0 (0.0)		0 (0.0)	0 (0.0)	
White and Black African (Mixed)	0 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
White and Asian (Mixed)	1 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
Any other Mixed background	1 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
Indian (Asian or Asian British)	114 (1.1)	7 (1.0)		22 (1.1)	7 (1.0)	
Pakistani (Asian or Asian British)	34 (0.3)	1 (0.1)		1 (0.0)	1 (0.1)	
Bangladeshi (Asian or Asian British)	6 (0.1)	0 (0.0)		0 (0.0)	0 (0.0)	
Any other Asian background	10 (0.1)	1 (0.1)		1 (0.0)	1 (0.1)	
Caribbean (Black or Black British)	44 (0.4)	1 (0.1)		2 (0.1)	1 (0.1)	
African (Black or Black British)	15 (0.1)	1 (0.1)		1 (0.0)	1 (0.1)	
Any other Black background	12 (0.1)	0 (0.0)		0 (0.0)	0 (0.0)	
Chinese (other ethnic group)	0 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
Any other ethnic group	24 (0.2)	2 (0.3)		3 (0.1)	2 (0.3)	
IMD decile (mean (sd))	5.75 (2.70)	5.88 (2.71)	0.049	5.98 (2.68)	5.88 (2.71)	0.037
Fixation (%)			0.244			0.033
Cementless	932 (8.9)	26 (3.8)		70 (3.4)	26 (3.8)	
Cemented	9411 (90.1)	640 (93.6)		1936 (94.3)	640 (93.6)	
Hybrid	98 (0.9)	18 (2.6)		46 (2.2)	18 (2.6)	

Cases per consultant per year (mean (sd))	91.12 (60.34)	89.63 (64.68)	0.024	89.96 (58.38)	89.63 (64.68)	0.005

Table A2.3 Patient characteristics before and after matching high usage UKRs (10+%) with TKRs for transition probabilities and hospital costs

	Before matching			After matching		
	TKR	UKR (usage 10+%)	SMD	TKR	UKR (usage 10+%)	SMD
Number of patients	75753	20686		60544	20682	
Age at surgery (mean (sd))	64.72 (9.30)	65.17 (9.41)	0.048	64.99 (9.27)	65.17 (9.41)	0.019
Unit type (%)			0.051			0.014
Public hospital	63990 (84.5)	17476 (84.5)		51198 (84.6)	17472 (84.5)	
Independent hospital	9098 (12.0)	2302 (11.1)		6852 (11.3)	2302 (11.1)	
Independent sector treatment centre	2665 (3.5)	908 (4.4)		2494 (4.1)	908 (4.4)	
Thromboprophylaxis						
Drugs (%)			0.118			0.039
Aspirin	9498 (12.5)	3364 (16.3)		9038 (14.9)	3362 (16.3)	
Direct thrombin inhibitor	2622 (3.5)	880 (4.3)		2444 (4.0)	879 (4.3)	
Unfractionated or low molecular weight heparin	397 (0.5)	92 (0.4)		281 (0.5)	92 (0.4)	
None/Unspecified	9325 (12.3)	2339 (11.3)		6989 (11.5)	2339 (11.3)	
Other	53187 (70.2)	13829 (66.9)		41248 (68.1)	13828 (66.9)	
Warfarin	724 (1.0)	182 (0.9)		544 (0.9)	182 (0.9)	
Mechanical (%)			0.099			0.029
None/Unspecified	9034 (11.9)	2486 (12.0)		7301 (12.1)	2486 (12.0)	
Foot pumps	7474 (9.9)	1659 (8.0)		5205 (8.6)	1659 (8.0)	
Intermittent calf compression	9166 (12.1)	3007 (14.5)		8319 (13.7)	3006 (14.5)	
Thromboembolic deterrent stockings	49069 (64.8)	13343 (64.5)		39144 (64.7)	13340 (64.5)	
Other	1010 (1.3)	191 (0.9)		575 (0.9)	191 (0.9)	
Gender (%)			0.017			0.005
M	39440 (52.1)	10656 (51.5)		31335 (51.8)	10655 (51.5)	
American Society of Anesthesiologists score (%)			0.033			0.027
1	16018 (21.1)	4299 (20.8)		12397 (20.5)	4299 (20.8)	
2	53087 (70.1)	14372 (69.5)		42685 (70.5)	14368 (69.5)	
3+	6648 (8.8)	2015 (9.7)		5462 (9.0)	2015 (9.7)	

Comorbidities (Charlson index) (%)			0.007			0.005
None	60768 (80.2)	16551 (80.0)		48502 (80.1)	16548 (80.0)	
Mild	12511 (16.5)	3459 (16.7)		10047 (16.6)	3459 (16.7)	
Moderate	1967 (2.6)	531 (2.6)		1584 (2.6)	530 (2.6)	
Severe	507 (0.7)	145 (0.7)		411 (0.7)	145 (0.7)	
Hypertension (mean (sd))	0.35 (0.48)	0.36 (0.48)	0.018	0.36 (0.48)	0.36 (0.48)	0.004
Ethnicity (%)			0.07			0.035
Undefined	9958 (13.1)	2944 (14.2)		8311 (13.7)	2944 (14.2)	
British (White)	61524 (81.2)	16506 (79.8)		48783 (80.6)	16505 (79.8)	
Irish (White)	411 (0.5)	123 (0.6)		355 (0.6)	123 (0.6)	
Any other White background	1401 (1.8)	440 (2.1)		1207 (2.0)	440 (2.1)	
White and Black Caribbean (Mixed)	29 (0.0)	13 (0.1)		29 (0.0)	13 (0.1)	
White and Black African (Mixed)	11 (0.0)	2 (0.0)		7 (0.0)	2 (0.0)	
White and Asian (Mixed)	42 (0.1)	16 (0.1)		42 (0.1)	16 (0.1)	
Any other Mixed background	31 (0.0)	11 (0.1)		30 (0.0)	11 (0.1)	
Indian (Asian or Asian British)	1068 (1.4)	265 (1.3)		802 (1.3)	265 (1.3)	
Pakistani (Asian or Asian British)	351 (0.5)	97 (0.5)		281 (0.5)	97 (0.5)	
Bangladeshi (Asian or Asian British)	26 (0.0)	6 (0.0)		23 (0.0)	6 (0.0)	
Any other Asian background	195 (0.3)	69 (0.3)		184 (0.3)	69 (0.3)	
Caribbean (Black or Black British)	259 (0.3)	52 (0.3)		175 (0.3)	52 (0.3)	
African (Black or Black British)	146 (0.2)	19 (0.1)		58 (0.1)	19 (0.1)	
Any other Black background	64 (0.1)	13 (0.1)		45 (0.1)	13 (0.1)	
Chinese (other ethnic group)	25 (0.0)	2 (0.0)		8 (0.0)	2 (0.0)	
Any other ethnic group	212 (0.3)	108 (0.5)		204 (0.3)	105 (0.5)	
IMD decile (mean (sd))	6.25 (2.67)	6.26 (2.68)	0.004	6.26 (2.67)	6.26 (2.68)	0.001
Fixation (%)			0.044			0.018
Cementless	5677 (7.5)	1704 (8.2)		4767 (7.9)	1704 (8.2)	
Cemented	68544 (90.5)	18461 (89.2)		54367 (89.8)	18459 (89.3)	
Hybrid	1532 (2.0)	521 (2.5)		1410 (2.3)	519 (2.5)	
Cases per consultant per year (mean (sd))	84.74 (58.78)	85.36 (55.18)	0.011	84.84 (58.89)	85.37 (55.18)	0.009

Table A2.4 Patient characteristics before and after matching high usage UKRs (10+%) with TKRs for quality of life

	Before matching			After matching		
	TKR	UKR (usage 10+%)	SMD	TKR	UKR (usage 10+%)	SMD
Number of patients	10441	2793		8379	2793	
Age at surgery (mean (sd))	64.38 (8.60)	65.01 (8.79)	0.073	64.96 (8.65)	65.01 (8.79)	0.005
Unit type (%)			0.079			0.024
Public hospital	7726 (74.0)	2072 (74.2)		6243 (74.5)	2072 (74.2)	
Independent hospital	2267 (21.7)	558 (20.0)		1692 (20.2)	558 (20.0)	
Independent sector treatment centre	448 (4.3)	163 (5.8)		444 (5.3)	163 (5.8)	
Thromboprophylaxis						
Drugs (%)			0.027			0.012
Aspirin	2065 (19.8)	538 (19.3)		1619 (19.3)	538 (19.3)	
Unfractionated or low molecular weight heparin	203 (1.9)	54 (1.9)		151 (1.8)	54 (1.9)	
None/Unspecified	2171 (20.8)	560 (20.1)		1694 (20.2)	560 (20.1)	
Other	5908 (56.6)	1614 (57.8)		4829 (57.6)	1614 (57.8)	
Warfarin	94 (0.9)	27 (1.0)		86 (1.0)	27 (1.0)	
Mechanical (%)			0.042			0.007
None/Unspecified	2428 (23.3)	635 (22.7)		1902 (22.7)	635 (22.7)	
Foot Pumps	887 (8.5)	226 (8.1)		677 (8.1)	226 (8.1)	
Intermittent calf compression	845 (8.1)	203 (7.3)		611 (7.3)	203 (7.3)	
Thromboembolic deterrent stockings	6154 (58.9)	1697 (60.8)		5087 (60.7)	1697 (60.8)	
Other	127 (1.2)	32 (1.1)		102 (1.2)	32 (1.1)	
Gender (%)			0.012			0.003
M	5511 (52.8)	1491 (53.4)		4462 (53.3)	1491 (53.4)	
American Society of Anesthesiologists score (%)			0.055			0.053
1	2183 (20.9)	605 (21.7)		1725 (20.6)	605 (21.7)	
2	7585 (72.6)	1973 (70.6)		6099 (72.8)	1973 (70.6)	
3+	673 (6.4)	215 (7.7)		555 (6.6)	215 (7.7)	
Comorbidities (Charlson index) (%)			0.063			0.017

None	8622 (82.6)	2296 (82.2)		6904 (82.4)	2296 (82.2)	
Mild	1496 (14.3)	398 (14.2)		1199 (14.3)	398 (14.2)	
Moderate	240 (2.3)	86 (3.1)		235 (2.8)	86 (3.1)	
Severe	83 (0.8)	13 (0.5)		41 (0.5)	13 (0.5)	
Hypertension (mean (sd))	0.35 (0.48)	0.36 (0.48)	0.025	0.35 (0.48)	0.36 (0.48)	0.008
Ethnicity (%)			0.064			0.016
Undefined	2253 (21.6)	606 (21.7)		1824 (21.8)	606 (21.7)	
British (White)	7643 (73.2)	2046 (73.3)		6129 (73.1)	2046 (73.3)	
Irish (White)	52 (0.5)	11 (0.4)		39 (0.5)	11 (0.4)	
Any other White background	225 (2.2)	66 (2.4)		201 (2.4)	66 (2.4)	
White and Black Caribbean (Mixed)	7 (0.1)	1 (0.0)		4 (0.0)	1 (0.0)	
White and Black African (Mixed)	0 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
White and Asian (Mixed)	1 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
Any other Mixed background	1 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
Indian (Asian or Asian British)	114 (1.1)	31 (1.1)		88 (1.1)	31 (1.1)	
Pakistani (Asian or Asian British)	34 (0.3)	10 (0.4)		28 (0.3)	10 (0.4)	
Bangladeshi (Asian or Asian British)	6 (0.1)	0 (0.0)		0 (0.0)	0 (0.0)	
Any other Asian background	10 (0.1)	2 (0.1)		5 (0.1)	2 (0.1)	
Caribbean (Black or Black British)	44 (0.4)	7 (0.3)		21 (0.3)	7 (0.3)	
African (Black or Black British)	15 (0.1)	4 (0.1)		12 (0.1)	4 (0.1)	
Any other Black background	12 (0.1)	1 (0.0)		4 (0.0)	1 (0.0)	
Chinese (other ethnic group)	0 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
Any other ethnic group	24 (0.2)	8 (0.3)		24 (0.3)	8 (0.3)	
IMD decile (mean (sd))	5.75 (2.70)	5.73 (2.75)	0.009	5.74 (2.72)	5.73 (2.75)	0.006
Fixation (%)			0.137			0.085
Cementless	932 (8.9)	322 (11.5)		912 (10.9)	322 (11.5)	
Cemented	9411 (90.1)	2409 (86.3)		7369 (87.9)	2409 (86.3)	
Hybrid	98 (0.9)	62 (2.2)		98 (1.2)	62 (2.2)	
Cases per consultant per year (mean (sd))	91.12 (60.34)	91.04 (54.59)	0.001	90.85 (60.48)	91.04 (54.59)	0.003

PARAMETRIC MODELS FOR REVISION AND MORTALITY

Figure A3.2 Parametric models for revision for male, <60 subgroups

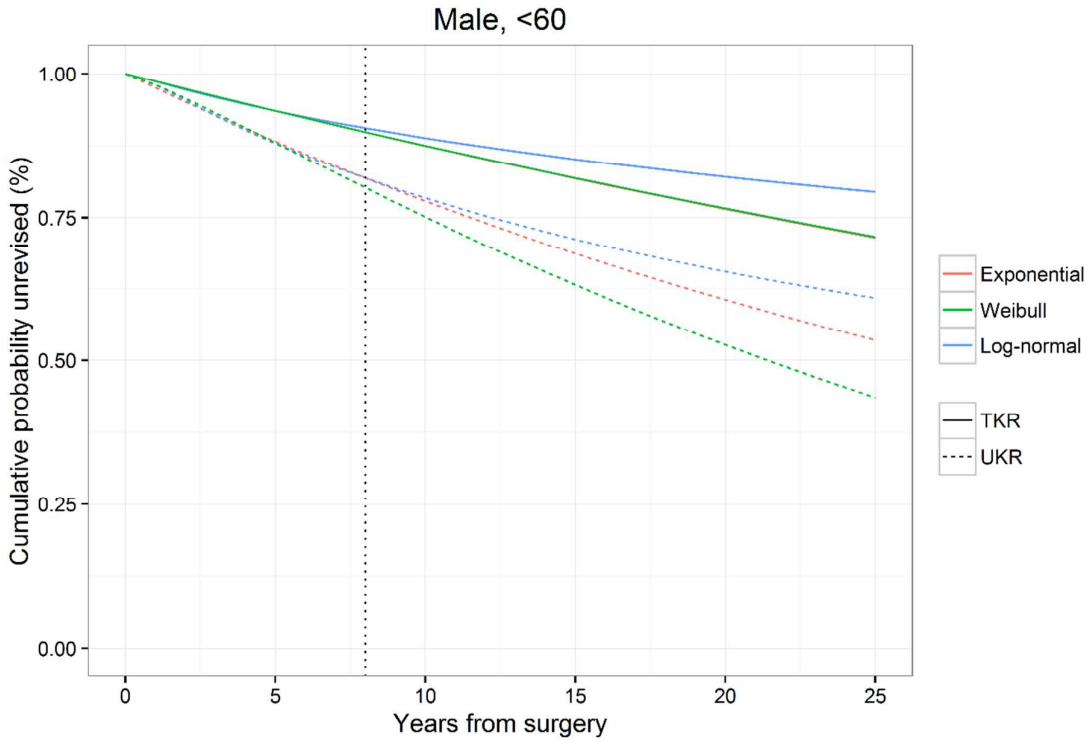

Table A3.3 AIC of parametric models for revision for male, <60 subgroups

Procedure	Distribution	AIC
TKR	Exponential	5,143
TKR	Weibull	5,145
TKR	Log-normal	5,123
UKR	Exponential	2,964
UKR	Weibull	2,957
UKR	Log-normal	2,949

Figure A3.2 Parametric models for revision for female, <60 subgroups

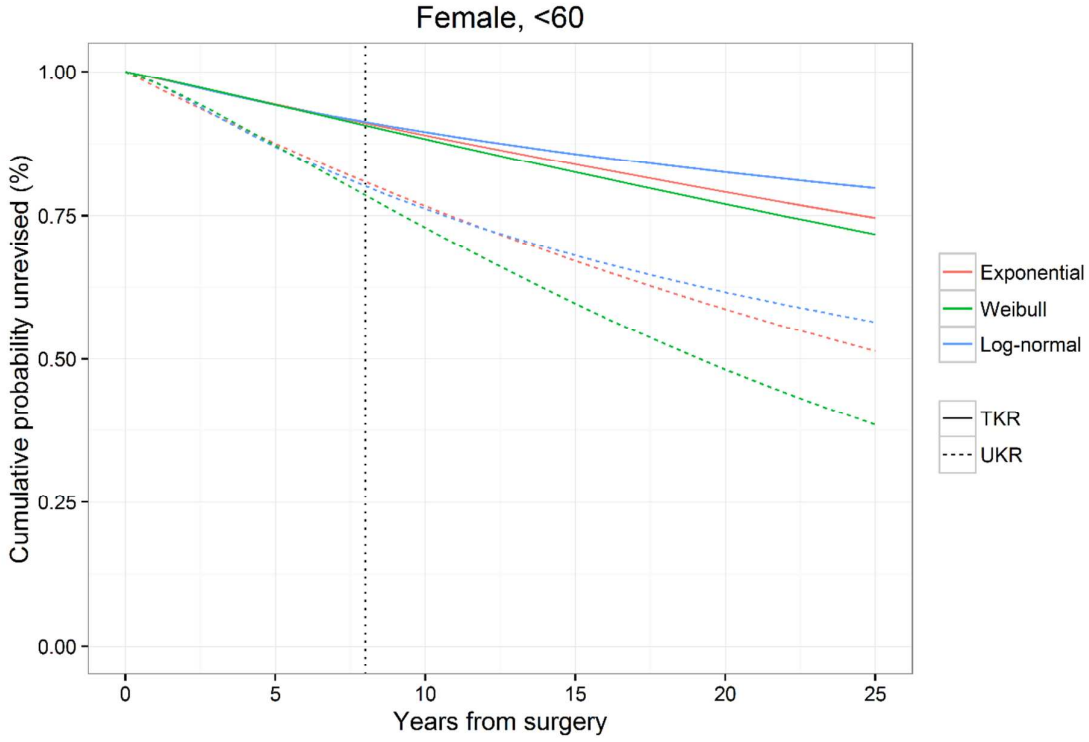

Table A3.2 AIC of parametric models for revision for female, <60 subgroups

Procedure	Distribution	AIC
TKR	Exponential	4,826
TKR	Weibull	4,826
TKR	Log-normal	4,799
UKR	Exponential	3,564
UKR	Weibull	3,548
UKR	Log-normal	3,525

Figure A3.3 Parametric models for revision for male, 60 to 75 subgroups

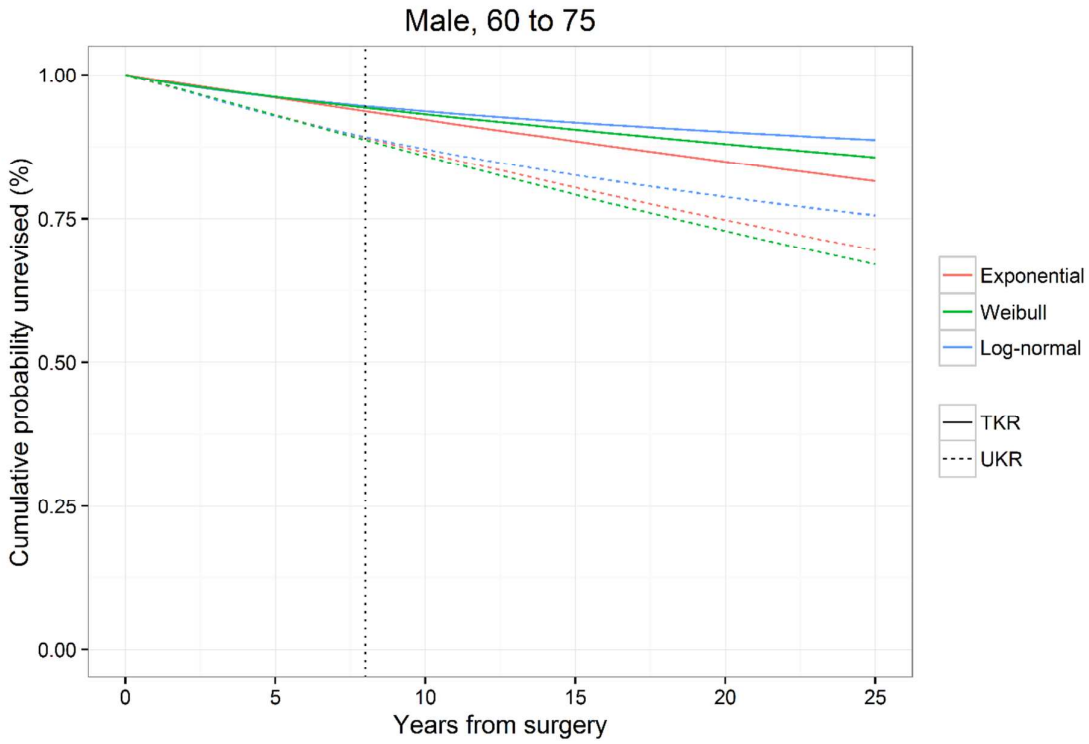

Table A3.3 AIC of parametric models for revision for male, 60 to 75 subgroups

Procedure	Distribution	AIC
TKR	Exponential	7,258
TKR	Weibull	7,237
TKR	Log-normal	7,197
UKR	Exponential	3,863
UKR	Weibull	3,863
UKR	Log-normal	3,833

Figure A3.4 Parametric models for revision for female, 60 to 75 subgroups

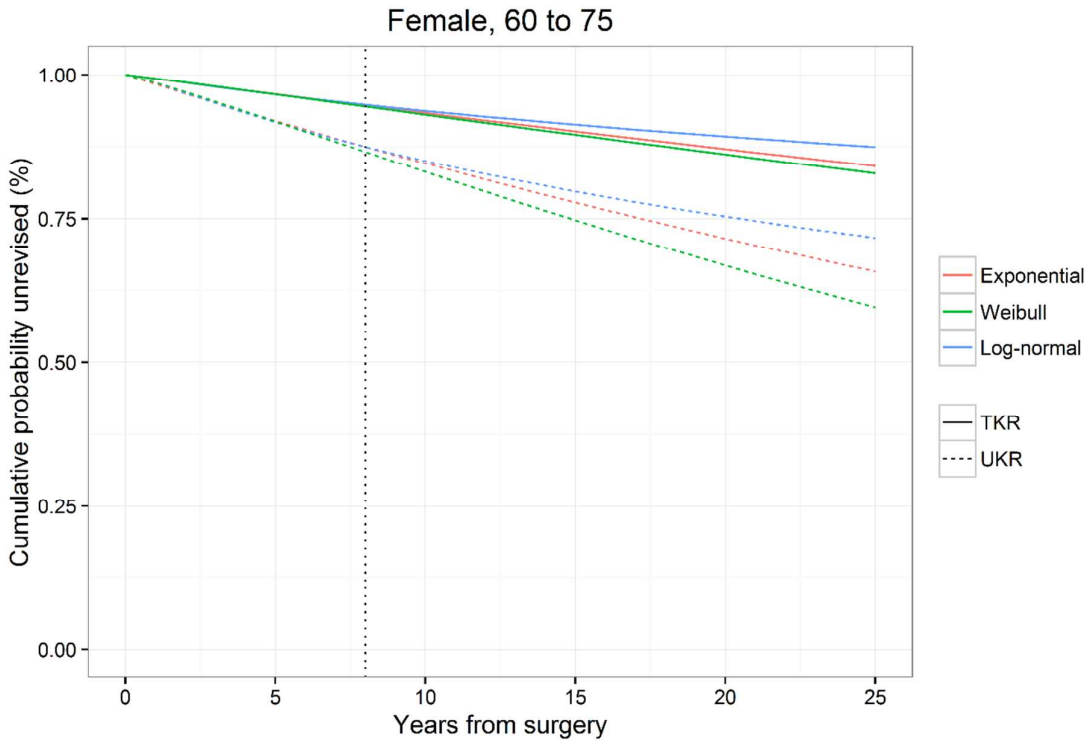

Table A3.4 AIC of parametric models for revision for female, 60 to 75 subgroups

Procedure	Distribution	AIC
TKR	Exponential	5,379
TKR	Weibull	5,380
TKR	Log-normal	5,359
UKR	Exponential	3,626
UKR	Weibull	3,622
UKR	Log-normal	3,608

Figure A3.5 Parametric models for revision for male, 75+ subgroups

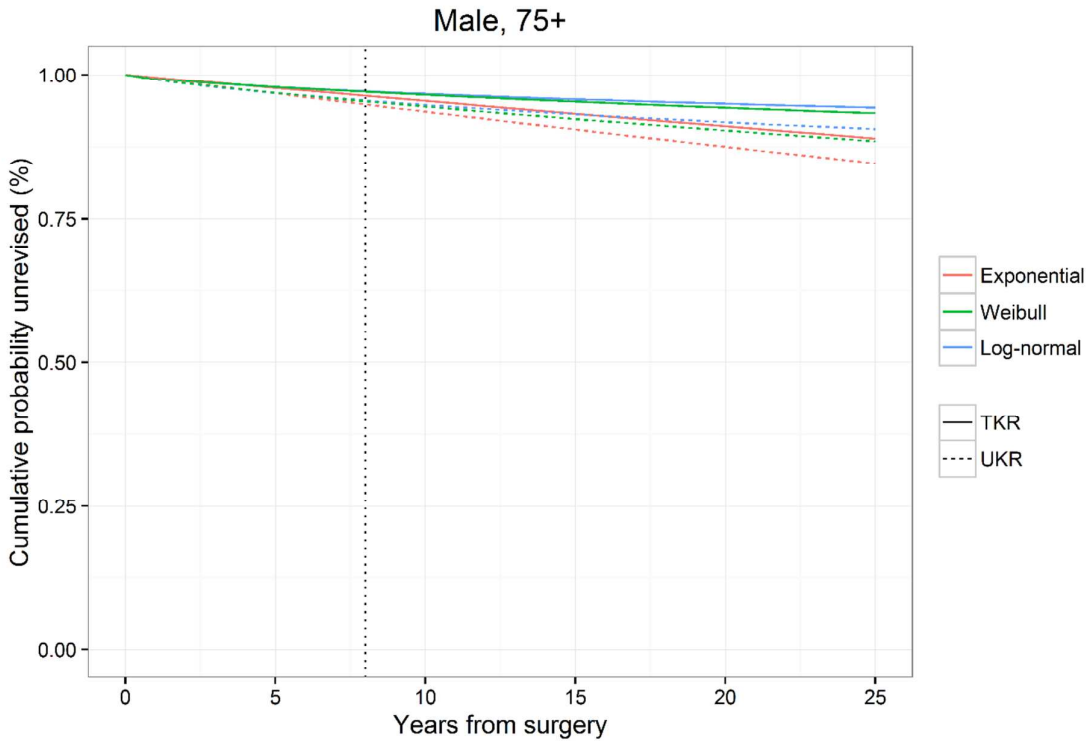

Table A3.5 AIC of parametric models for revision for male, 75+ subgroups

Procedure	Distribution	AIC
TKR	Exponential	1,020
TKR	Weibull	1,011
TKR	Log-normal	1,004
UKR	Exponential	507
UKR	Weibull	507
UKR	Log-normal	503

Figure A3.6 Parametric models for revision for female, 75+ subgroups

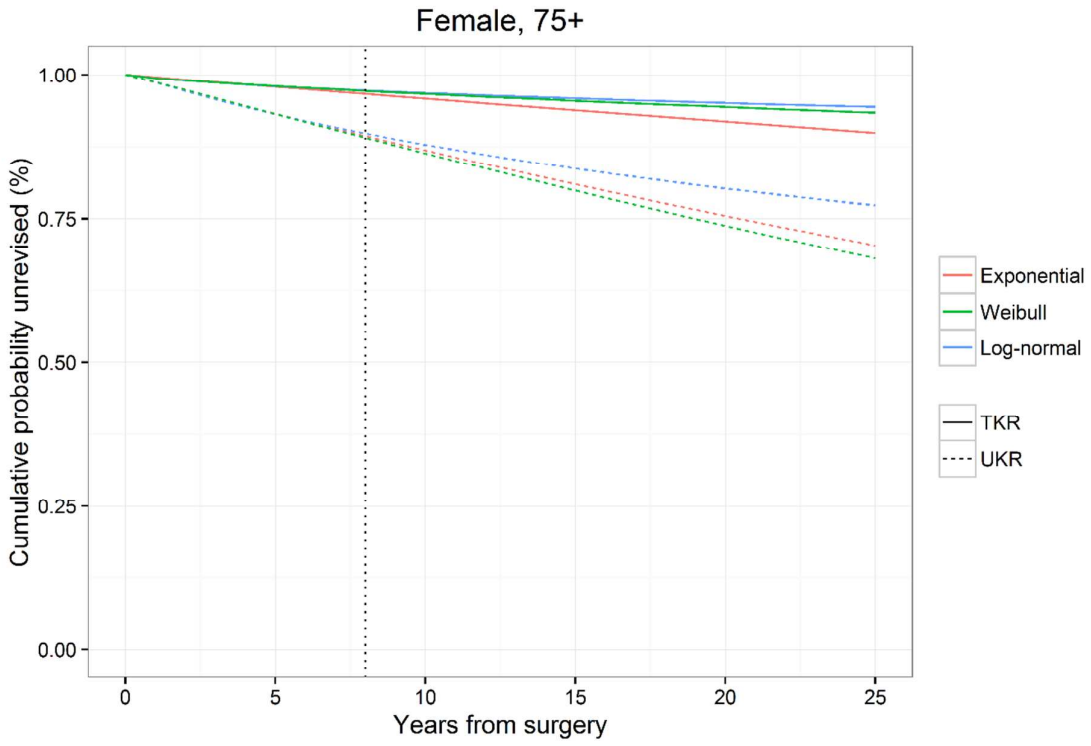

Table A3.6 AIC of parametric models for revision for female, 75+ subgroups

Procedure	Distribution	AIC
TKR	Exponential	997
TKR	Weibull	991
TKR	Log-normal	985
UKR	Exponential	949
UKR	Weibull	951
UKR	Log-normal	949

Figure A3.7 Parametric models for revision for usage, <10 subgroups

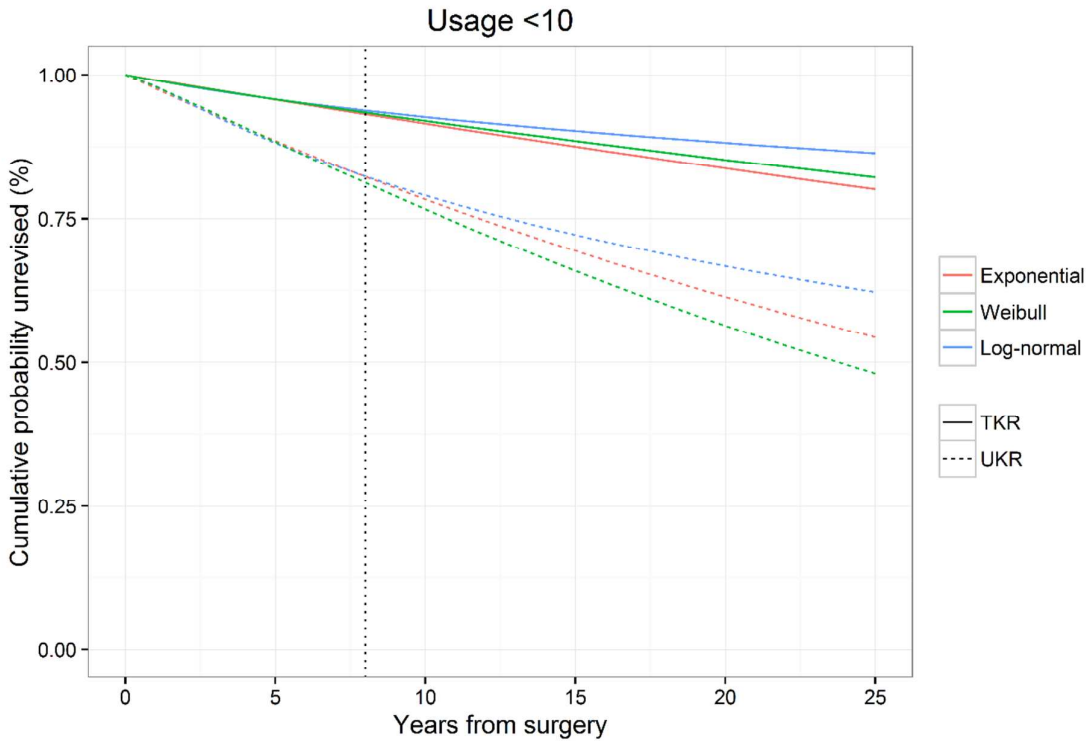

Table A3.7 AIC of parametric models for revision for usage, <10 subgroups

Procedure	Distribution	AIC
TKR	Exponential	4,615
TKR	Weibull	4,614
TKR	Log-normal	4,591
UKR	Exponential	3,566
UKR	Weibull	3,563
UKR	Log-normal	3,534

Figure A3.8 Parametric models for revision for usage, 10+ subgroups

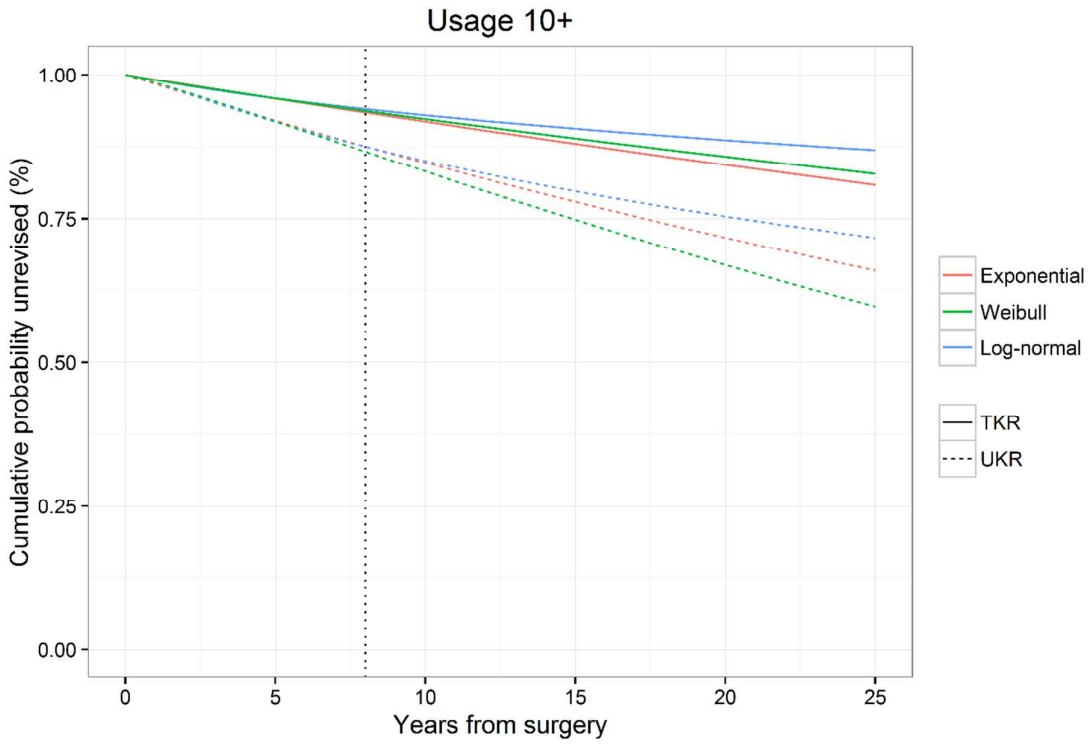

Table A3.8 AIC of parametric models for revision for usage, 10+ subgroups

Procedure	Distribution	AIC
TKR	Exponential	19,665
TKR	Weibull	19,657
TKR	Log-normal	19,563
UKR	Exponential	12,028
UKR	Weibull	12,010
UKR	Log-normal	11,956

Figure A3.9 Parametric models for mortality for male, <60 subgroups

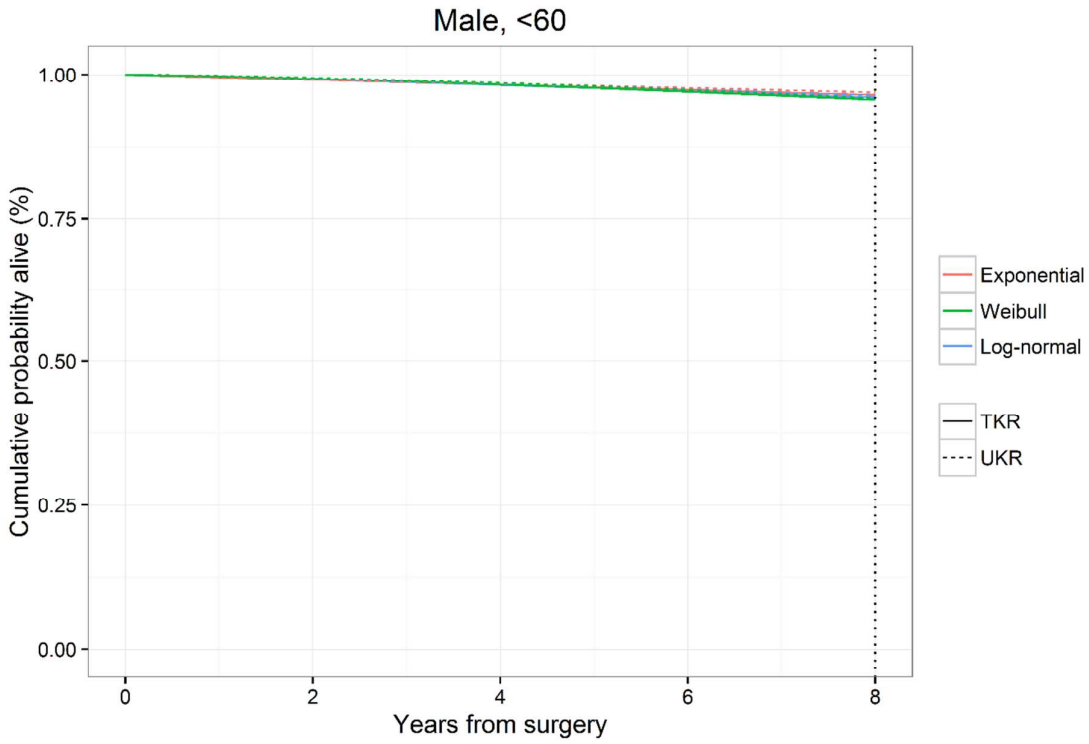

Table A3.9 AIC of parametric models for mortality for male, <60 subgroups

Procedure	Distribution	AIC
TKR	Exponential	2110
TKR	Weibull	2093
TKR	Log-normal	2096
UKR	Exponential	666
UKR	Weibull	657
UKR	Log-normal	662

Figure A3.10 Parametric models for mortality for female, <60 subgroups

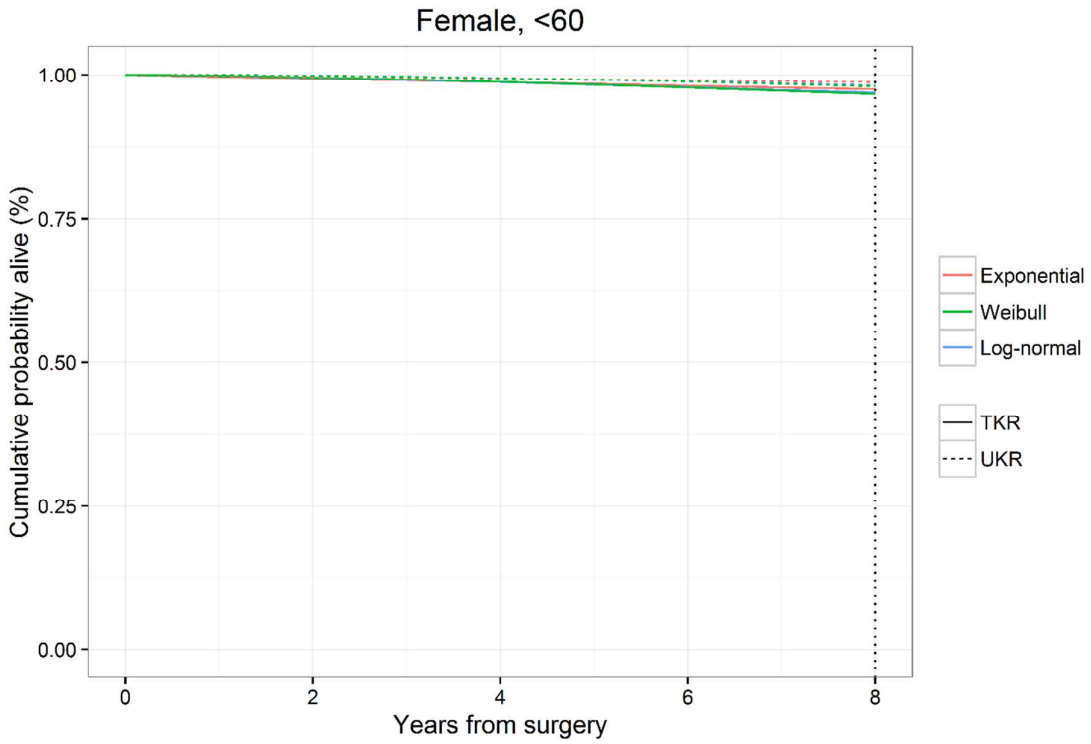

Table A3.10 AIC of parametric models for mortality for female, <60 subgroups

Procedure	Distribution	AIC
TKR	Exponential	1657
TKR	Weibull	1637
TKR	Log-normal	1635
UKR	Exponential	357
UKR	Weibull	348
UKR	Log-normal	349

Figure A3.11 Parametric models for mortality for male, 60 to 75 subgroups

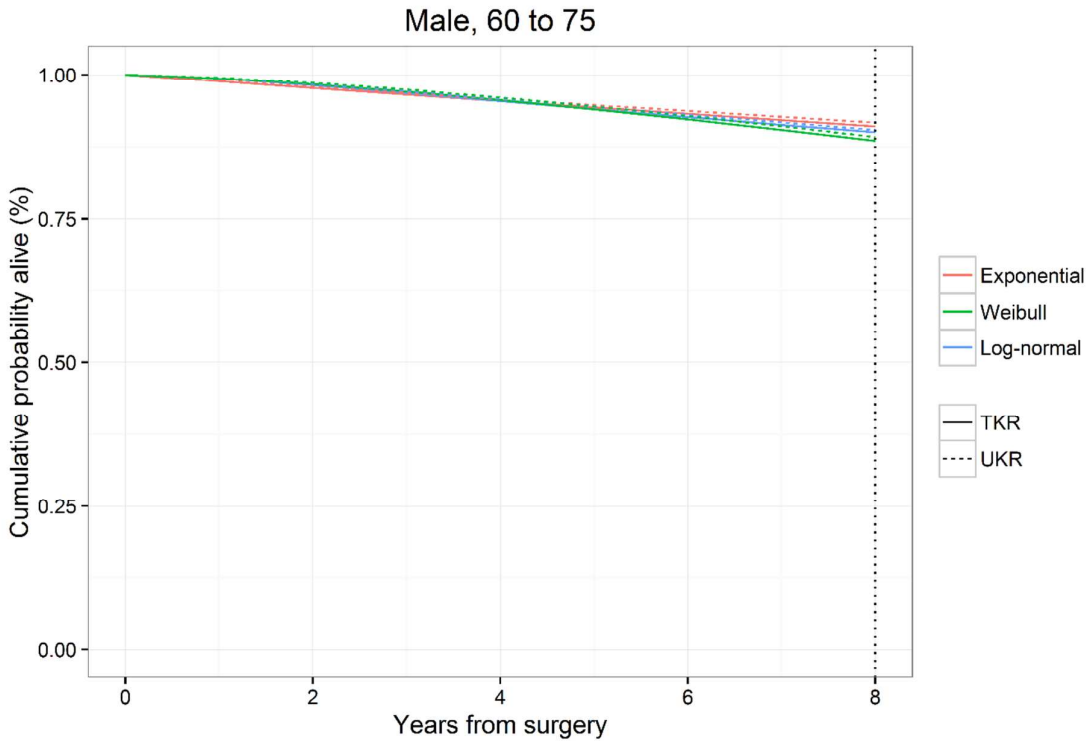

Table A3.11 AIC of parametric models for mortality for male, 60 to 75 subgroups

Procedure	Distribution	AIC
TKR	Exponential	9758
TKR	Weibull	9617
TKR	Log-normal	9676
UKR	Exponential	3050
UKR	Weibull	2996
UKR	Log-normal	3010

Figure A3.12 Parametric models for mortality for female, 60 to 75 subgroups

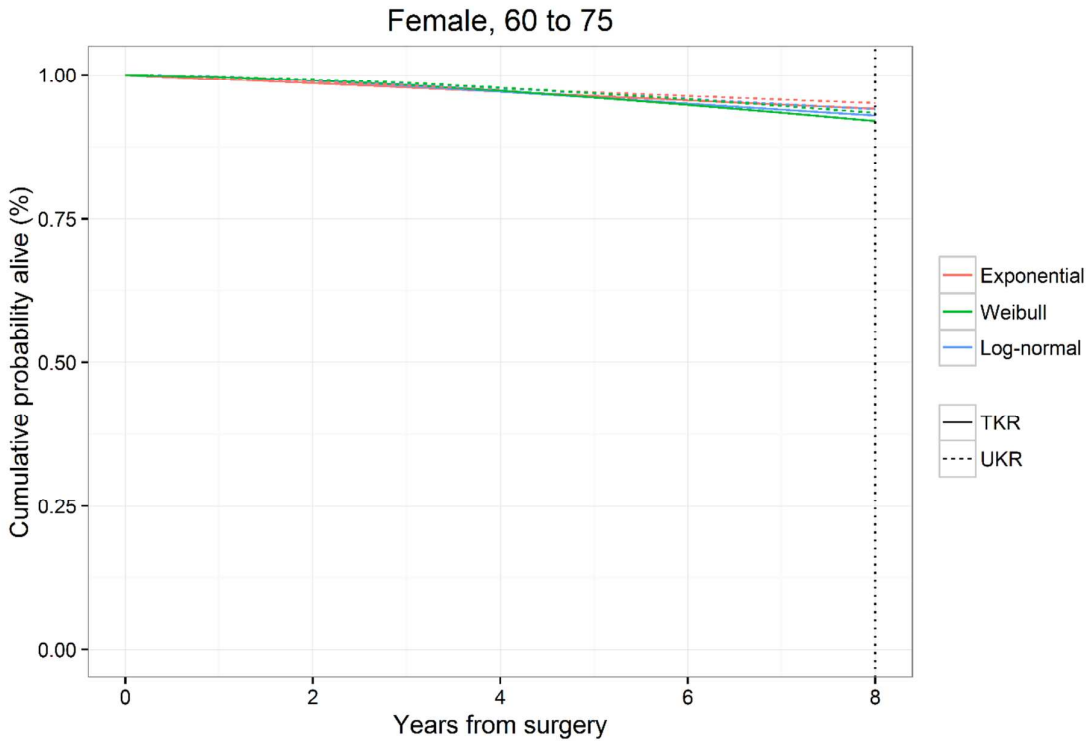

Table A3.12 AIC of parametric models for mortality for female, 60 to 75 subgroups

Procedure	Distribution	AIC
TKR	Exponential	5852
TKR	Weibull	5736
TKR	Log-normal	5764
UKR	Exponential	1638
UKR	Weibull	1606
UKR	Log-normal	1610

Figure A3.13 Parametric models for mortality for male, 75+ subgroups

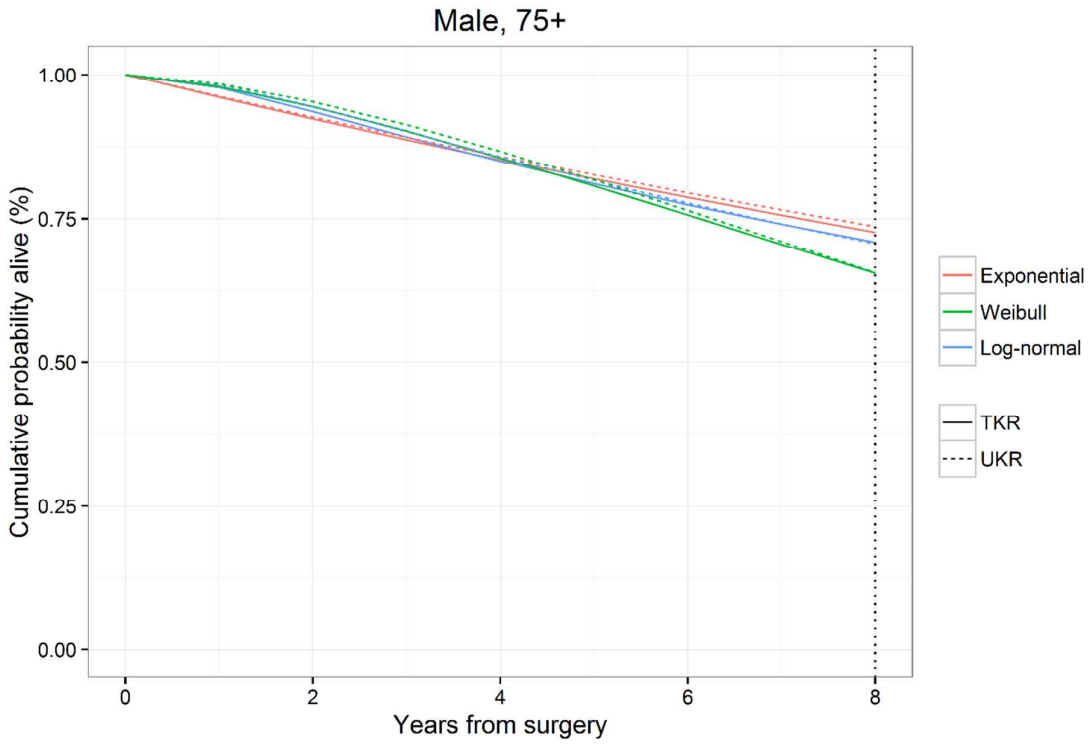

Table A3.13 AIC of parametric models for mortality for male, 75+ subgroups

Procedure	Distribution	AIC
TKR	Exponential	5758
TKR	Weibull	5645
TKR	Log-normal	5712
UKR	Exponential	2057
UKR	Weibull	1998
UKR	Log-normal	2026

Figure A3.14 Parametric models for mortality for female, 75+ subgroups

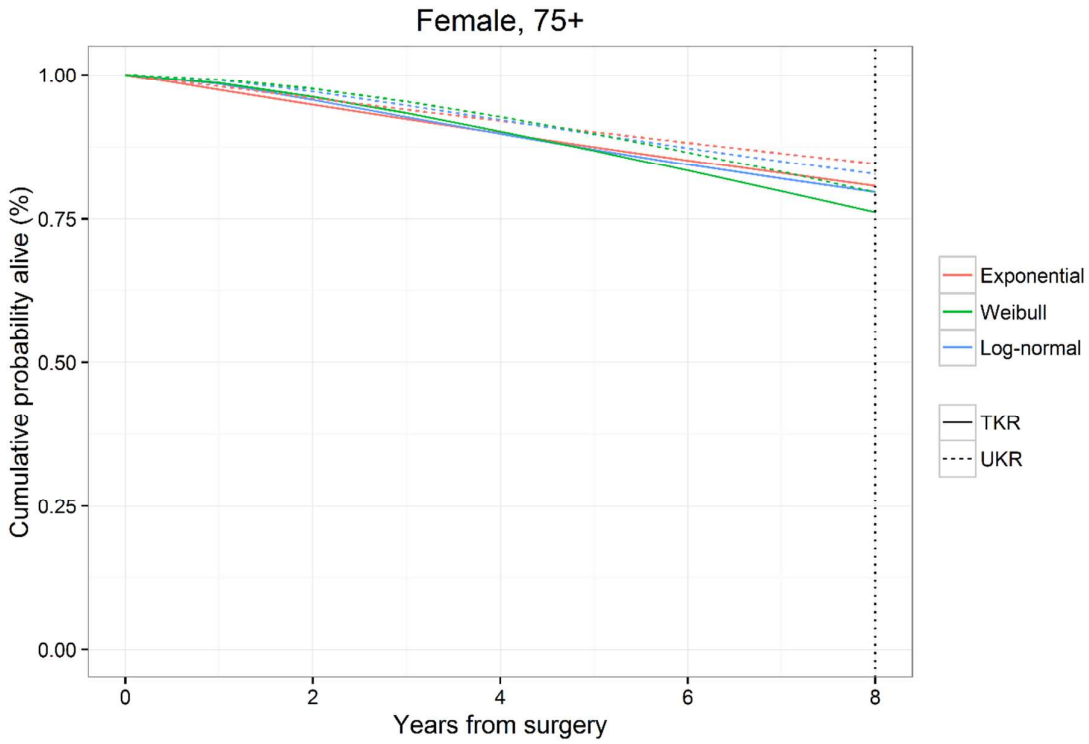

Table A3.14 AIC of parametric models for mortality for female, 75+ subgroups

Procedure	Distribution	AIC
TKR	Exponential	4482
TKR	Weibull	4415
TKR	Log-normal	4462
UKR	Exponential	1306
UKR	Weibull	1272
UKR	Log-normal	1293

Figure A3.15 Parametric models for mortality for usage, <10 subgroups

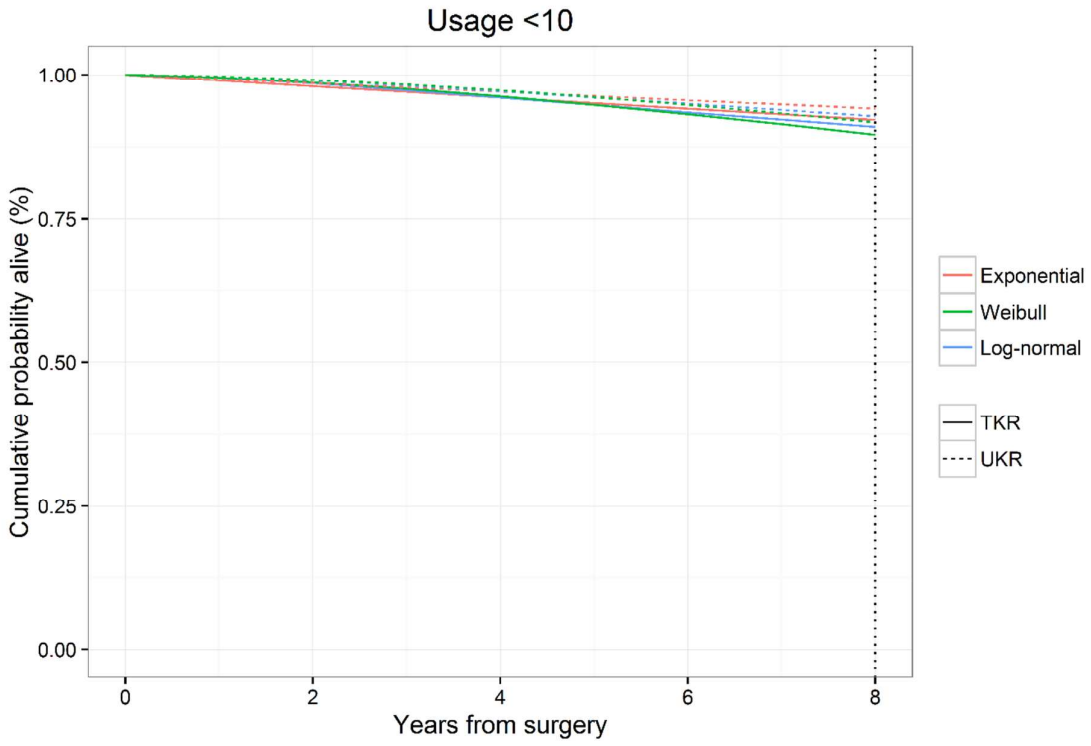

Table A3.15 AIC of parametric models for mortality for usage, <10 subgroups

Procedure	Distribution	AIC
TKR	Exponential	5164
TKR	Weibull	5069
TKR	Log-normal	5103
UKR	Exponential	1389
UKR	Weibull	1355
UKR	Log-normal	1366

Figure A3.16 Parametric models for mortality for usage, 10+ subgroups

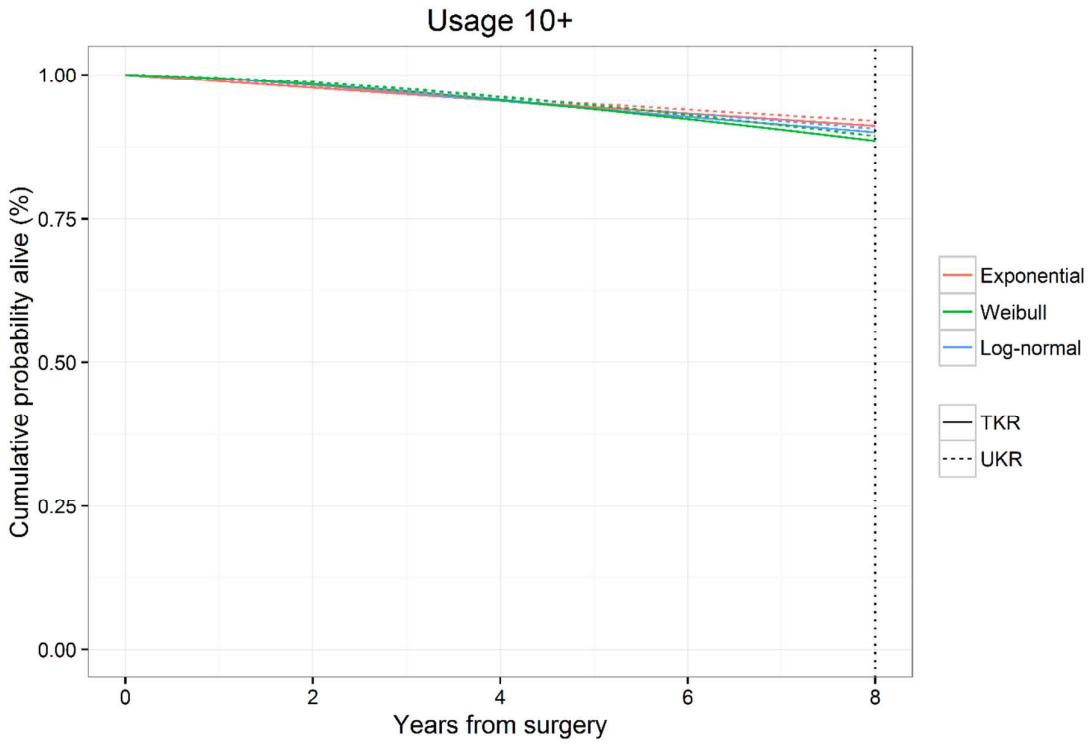

Table A3.16 AIC of parametric models for mortality for usage, 10+ subgroups

Procedure	Distribution	AIC
TKR	Exponential	25418
TKR	Weibull	25025
TKR	Log-normal	25187
UKR	Exponential	8262
UKR	Weibull	8094
UKR	Log-normal	8146

COSTS

Table A4.1 Hospital costs

	Procedure	Subgroup	N	Mean	SD	SE
Primary						
	TKR	<60, Female	10287	5968	1070	33
	UKR	<60, Female	3270	3910	2259	48
	TKR	<60, Male	10856	5965	1107	33
	UKR	<60, Male	3857	3935	2274	48
	TKR	60 to 70, Female	21480	6013	992	31
	UKR	60 to 70, Female	6567	3996	2257	48
	TKR	60 to 70, Male	18249	6047	988	31
	UKR	60 to 70, Male	5493	3996	2226	47
	TKR	>75, Female	5033	6186	1266	36
	UKR	>75, Female	1702	4035	2276	48
	TKR	>75, Male	5098	6131	1126	34
	UKR	>75, Male	1619	3993	2249	47
	TKR	<10	53832	6041	991	31
	UKR	<10	4210	4070	2224	47
	TKR	10+	15542	6002	1223	35
	UKR	10+	18213	3947	2260	48
Reoperation						
	TKR	<60, Female	497	2384	1979	44
	UKR	<60, Female	171	1822	1558	39
	TKR	<60, Male	549	2122	1776	42
	UKR	<60, Male	206	1680	1183	34
	TKR	60 to 70, Female	689	2361	2124	46
	UKR	60 to 70, Female	203	2220	2036	45
	TKR	60 to 70, Male	590	2258	2188	47
	UKR	60 to 70, Male	148	1929	1817	43

	TKR	>75, Female	114	2962	3158	56
	UKR	>75, Female	27	2496	2772	53
	TKR	>75, Male	107	2174	2045	45
	UKR	>75, Male	40	1973	2353	49
	TKR	<10	819	2323	2138	46
	UKR	<10	73	1577	1367	37
	TKR	10+	240	2291	2008	45
	UKR	10+	276	2104	1957	44
Revision						
	TKR	<60, Female	470	8154	2775	53
	UKR	<60, Female	300	6385	2507	50
	TKR	<60, Male	428	7937	2534	50
	UKR	<60, Male	367	6210	2379	49
	TKR	60 to 70, Female	598	7866	3748	61
	UKR	60 to 70, Female	347	6607	2365	49
	TKR	60 to 70, Male	428	8045	2684	52
	UKR	60 to 70, Male	326	6492	2364	49
	TKR	>75, Female	73	7820	3079	55
	UKR	>75, Female	39	6876	1824	43
	TKR	>75, Male	72	8049	2742	52
	UKR	>75, Male	85	6844	2145	46
	TKR	<10	643	7924	3541	60
	UKR	<10	189	6867	2410	49
	TKR	10+	216	8233	2443	49
	UKR	10+	541	6491	2352	48

Table A4.2 Primary care costs

Patient characteristics

	Before matching			After matching		
	TKR	UKR	SMD	TKR	UKR	SMD
Number of individuals	23,290	335		1,005	335	
Age at primary (mean (sd))	70.86 (8.79)	66.58 (9.74)	0.462	66.69 (9.26)	66.58 (9.74)	0.012
Gender: female (%)	13409 (57.6)	168 (50.1)	0.149	481 (47.9)	168 (50.1)	0.046
Year of primary (median [IQR])	2005 [2001, 2008]	2006 [2004, 2008]	0.469	2007 [2004, 2009]	2006 [2004, 2008]	0.004
Pain-related prescription costs in year prior to primary (median [IQR])	21 [2, 84]	16 [2, 59]	0.166	17 [2, 65]	16 [2, 59]	0.021
Consultation costs in year prior to primary (median [IQR])	322 [176, 552]	368 [184, 598]	0.142	368 [184, 644]	368 [184, 598]	0.007
Comorbidities at index date						
Chronic pulmonary disease (mean (sd))	0.20 (0.40)	0.15 (0.36)	0.132	0.16 (0.37)	0.15 (0.36)	0.025
Rheumatological disease (mean (sd))	0.07 (0.25)	0.05 (0.22)	0.068	0.05 (0.22)	0.05 (0.22)	0.005
Cerebrovascular disease (mean (sd))	0.05 (0.22)	0.03 (0.16)	0.135	0.03 (0.17)	0.03 (0.16)	0.012
Diabetes (mean (sd))	0.10 (0.30)	0.10 (0.29)	0.005	0.09 (0.29)	0.10 (0.29)	0.017
Myocardial infarction (mean (sd))	0.04 (0.21)	0.03 (0.18)	0.059	0.04 (0.19)	0.03 (0.18)	0.027
Congestive heart disease (mean (sd))	0.03 (0.17)	0.02 (0.13)	0.078	0.01 (0.12)	0.02 (0.13)	0.032
Renal disease (mean (sd))	0.07 (0.25)	0.07 (0.26)	0.029	0.07 (0.26)	0.07 (0.26)	<0.001
Cancer (mean (sd))	0.08 (0.27)	0.05 (0.21)	0.123	0.05 (0.22)	0.05 (0.21)	0.009
Metastatic tumour (mean (sd))	0.00 (0.05)	0.00 (0.05)	<0.001	0.00 (0.06)	0.00 (0.05)	0.017
Diabetes with complications (mean (sd))	0.02 (0.13)	0.02 (0.13)	0.016	0.02 (0.13)	0.02 (0.13)	<0.001
Peptic ulcer disease (mean (sd))	0.06 (0.23)	0.05 (0.22)	0.024	0.06 (0.24)	0.05 (0.22)	0.035
Peripheral vascular disease (mean (sd))	0.03 (0.17)	0.01 (0.12)	0.11	0.02 (0.14)	0.01 (0.12)	0.031
Dementia (mean (sd))	0.00 (0.05)	0.00 (0.00)	0.066	0.00 (0.00)	0.00 (0.00)	-
Mild liver disease (mean (sd))	0.00 (0.06)	0.01 (0.08)	0.042	0.01 (0.08)	0.01 (0.08)	<0.001
Hemiplegia (mean (sd))	0.00 (0.05)	0.00 (0.00)	0.066	0.00 (0.00)	0.00 (0.00)	-
Liver disease (mean (sd))	0.00 (0.02)	0.00 (0.00)	0.032	0.00 (0.00)	0.00 (0.00)	-

AIDS (mean (sd))		0.00 (0.01)	0.00 (0.00)	0.009	0.00 (0.00)	0.00 (0.00)	-

Costs

	N	Mean	SD	SE
<60, Male	82	328	301	33
60 to 70, Male	175	431	334	25
>75, Male	57	640	497	66
<60, Female	54	503	431	59
60 to 70, Female	164	478	406	32
>75, Female	62	554	418	53
All	594	471	396	16

QUALITY OF LIFE

Table A5.1 EQ-5D index scores

	Procedure	Subgroup	N	Pre-op			Post-op		
				Mean	SD	SE	Mean	SD	SE
Primary									
	TKR	<60, Male	1,487	0.44	0.30	0.008	0.70	0.28	0.007
	TKR	<60, Female	1,613	0.39	0.31	0.008	0.69	0.28	0.007
	TKR	60 to 70, Male	3,456	0.54	0.27	0.005	0.78	0.23	0.004
	TKR	60 to 70, Female	2,850	0.47	0.29	0.005	0.76	0.23	0.004
	TKR	>75, Male	641	0.56	0.25	0.010	0.79	0.21	0.008
	TKR	>75, Female	510	0.47	0.29	0.013	0.77	0.22	0.010
	UKR	<60, Male	473	0.44	0.30	0.014	0.71	0.29	0.013
	UKR	<60, Female	592	0.39	0.32	0.013	0.69	0.30	0.012
	UKR	60 to 70, Male	1,155	0.53	0.27	0.008	0.81	0.21	0.006
	UKR	60 to 70, Female	882	0.49	0.28	0.009	0.78	0.24	0.008
	UKR	>75, Male	241	0.54	0.25	0.016	0.84	0.18	0.012
	UKR	>75, Female	176	0.47	0.30	0.023	0.81	0.20	0.015
	TKR	<10	2,052	0.46	0.30	0.007	0.74	0.26	0.006
	UKR	<10	684	0.45	0.29	0.011	0.73	0.27	0.010
	TKR	10+	8,379	0.49	0.29	0.000	0.75	0.24	0.003
	UKR	10+	2,793	0.49	0.29	0.010	0.78	0.24	0.005
Revision									
	TKR		686	0.31	0.32	0.012	0.55	0.32	0.012
	UKR		248	0.38	0.31	0.020	0.61	0.27	0.017

SENSITIVITY ANALYSES.

Distribution of parametric model for revision risk: exponential

	TKR		UKR				
	QALYs	Costs	QALYs	Costs	Δ QALYs	Δ Costs	ICER (probability cost-effective*)
Male, <60	10.28 (10.06 to 10.47)	15,367 (14,690 to 16,020)	10.43 (10.13 to 10.72)	13,701 (12,986 to 14,370)	0.16 (-0.17 to 0.50)	-1,666 (-1,931 to -1,411)	UKR dominant (92%)
Male, 60-75	8.58 (8.49 to 8.68)	13,455 (12,710 to 14,286)	8.82 (8.66 to 8.97)	11,877 (11,114 to 12,696)	0.24 (0.05 to 0.41)	-1,578 (-1,796 to -1,382)	UKR dominant (100%)
Male, 75+	5.60 (5.48 to 5.71)	11,529 (10,591 to 12,639)	5.80 (5.64 to 5.95)	9,503 (8,515 to 10,620)	0.19 (0.01 to 0.37)	-2,026 (-2,214 to -1,833)	UKR dominant (100%)
Female, <60	10.70 (10.48 to 10.90)	16,794 (15,959 to 17,745)	10.81 (10.46 to 11.12)	15,743 (14,831 to 16,688)	0.11 (-0.28 to 0.45)	-1,050 (-1,384 to -747)	UKR dominant (78%)
Female, 60-75	8.97 (8.86 to 9.08)	13,764 (12,993 to 14,538)	9.27 (9.07 to 9.47)	12,664 (11,831 to 13,500)	0.30 (0.08 to 0.51)	-1,100 (-1,320 to -874)	UKR dominant (100%)
Female, 75+	6.01 (5.81 to 6.16)	11,483 (10,584 to 12,437)	6.46 (6.19 to 6.70)	10,264 (9,265 to 11,236)	0.45 (0.16 to 0.75)	-1,220 (-1,495 to -940)	UKR dominant (100%)

Expected (mean) values with 95% confidence intervals in parentheses. UKR is considered 'dominant' if it is expected to improve health outcomes and reduce health care costs. *Given a cost-effectiveness threshold of £20,000.

Distribution of parametric model for revision risk: Log-normal

	TKR			UKR				
	Proportion revised	QALYs	Costs	QALYs	Costs	Δ QALYs	Δ Costs	ICER (probability cost-effective*)
Male, <60	19.2% (16.9% to 21.8%)	10.35 (10.14 to 10.56)	14,812 (14,135 to 15,507)	10.49 (10.16 to 10.82)	13,071 (12,350 to 13,798)	0.14 (-0.22 to 0.47)	-1,742 (-2,018 to -1,447)	UKR dominant (89%)
Male, 60-75	8.6% (7.3% to 10.1%)	8.62 (8.53 to 8.71)	13,186 (12,471 to 13,977)	8.86 (8.69 to 9.00)	11,643 (10,936 to 12,441)	0.23 (0.04 to 0.40)	-1,544 (-1,779 to -1,292)	UKR dominant (100%)
Male, 75+	3.3% (1.6% to 6.4%)	5.61 (5.50 to 5.72)	11,438 (10,519 to 12,541)	5.81 (5.63 to 5.96)	9,421 (8,456 to 10,529)	0.19 (0.01 to 0.36)	-2,017 (-2,358 to -1,613)	UKR dominant (100%)
Female, <60	20.1% (17.5% to 22.6%)	10.75 (10.54 to 10.95)	16,367 (15,426 to 17,302)	10.84 (10.50 to 11.15)	15,081 (14,165 to 15,958)	0.08 (-0.29 to 0.45)	-1,286 (-1,615 to -958)	UKR dominant (77%)
Female, 60-75	9.9% (8.2% to 11.9%)	8.99 (8.88 to 9.10)	13,621 (12,870 to 14,439)	9.31 (9.10 to 9.50)	12,364 (11,581 to 13,152)	0.32 (0.08 to 0.54)	-1,257 (-1,524 to -1,013)	UKR dominant (100%)
Female, 75+	3.4% (1.8% to 6.5%)	6.02 (5.80 to 6.16)	11,389 (10,524 to 12,368)	6.47 (6.16 to 6.70)	10,108 (9,168 to 11,159)	0.45 (0.16 to 0.73)	-1,281 (-1,685 to -897)	UKR dominant (100%)

Expected (mean) values with 95% confidence intervals in parentheses. UKR is considered 'dominant' if it is expected to improve health outcomes and reduce health care costs. *Given a cost-effectiveness threshold of £20,000.

Health utility: re-revision equal to revision

	TKR		UKR				
	QALYs	Costs	QALYs	Costs	Δ QALYs	Δ Costs	ICER (probability cost-effective*)
Male, <60	10.32 (10.06 to 10.47)	15,357 (14,706 to 16,016)	10.49 (10.18 to 10.82)	14,134 (13,472 to 14,795)	0.16 (-0.11 to 0.57)	-1,223 (-1,417 to -988)	UKR dominant (95%)
Male, 60-75	8.62 (8.51 to 8.70)	13,307 (12,563 to 14,052)	8.83 (8.68 to 8.98)	11,952 (11,199 to 12,717)	0.21 (0.04 to 0.41)	-1,355 (-1,594 to -1,131)	UKR dominant (100%)
Male, 75+	5.61 (5.49 to 5.72)	11,454 (10,515 to 12,565)	5.81 (5.64 to 5.96)	9,450 (8,476 to 10,614)	0.19 (0.01 to 0.38)	-2,005 (-2,457 to -1,480)	UKR dominant (100%)
Female, <60	10.73 (10.46 to 10.86)	16,961 (16,099 to 17,907)	10.90 (10.57 to 11.22)	16,360 (15,480 to 17,287)	0.17 (-0.14 to 0.62)	-601 (-867 to -346)	UKR dominant (91%)
Female, 60-75	8.98 (8.85 to 9.07)	13,814 (13,019 to 14,606)	9.28 (9.09 to 9.47)	12,878 (12,108 to 13,711)	0.30 (0.09 to 0.54)	-935 (-1,192 to -685)	UKR dominant (100%)
Female, 75+	6.03 (5.81 to 6.17)	11,410 (10,487 to 12,500)	6.50 (6.24 to 6.72)	10,308 (9,377 to 11,399)	0.47 (0.21 to 0.75)	-1,102 (-1,622 to -667)	UKR dominant (100%)

Expected (mean) values with 95% confidence intervals in parentheses. UKR is considered 'dominant' if it is expected to improve health outcomes and reduce health care costs. *Given a cost-effectiveness threshold of £20,000.

Cost: cost of re-revision 50% higher than revision

	TKR		UKR				
	QALYs	Costs	QALYs	Costs	Δ QALYs	Δ Costs	ICER (probability cost-effective*)
Male, <60	10.28 (10.06 to 10.47)	13,638 (13,060 to 14,237)	10.39 (10.09 to 10.69)	12,415 (11,859 to 13,039)	0.12 (-0.23 to 0.45)	-1,223 (-1,432 to -1,028)	UKR dominant (83%)
Male, 60-75	8.61 (8.50 to 8.70)	13,307 (12,571 to 14,151)	8.81 (8.66 to 8.96)	11,952 (11,219 to 12,817)	0.20 (0.03 to 0.39)	-1,355 (-1,598 to -1,103)	UKR dominant (100%)
Male, 75+	5.61 (5.48 to 5.72)	11,454 (10,460 to 12,626)	5.80 (5.63 to 5.96)	9,450 (8,503 to 10,679)	0.19 (0.00 to 0.37)	-2,005 (-2,445 to -1,542)	UKR dominant (100%)
Female, <60	10.68 (10.48 to 10.88)	16,961 (15,994 to 17,808)	10.78 (10.44 to 11.06)	16,360 (15,406 to 17,199)	0.10 (-0.33 to 0.46)	-601 (-893 to -348)	UKR dominant (73%)
Female, 60-75	8.96 (8.85 to 9.08)	13,814 (13,026 to 14,588)	9.24 (9.05 to 9.44)	12,878 (12,050 to 13,727)	0.28 (0.04 to 0.51)	-935 (-1,168 to -705)	UKR dominant (100%)
Female, 75+	6.02 (5.82 to 6.16)	11,410 (10,541 to 12,425)	6.46 (6.17 to 6.68)	10,308 (9,362 to 11,339)	0.44 (0.15 to 0.73)	-1,102 (-1,623 to -683)	UKR dominant (100%)

Expected (mean) values with 95% confidence intervals in parentheses. UKR is considered 'dominant' if it is expected to improve health outcomes and reduce health care costs. *Given a cost-effectiveness threshold of £20,000.

Consolidated Health Economic Evaluation Reporting Standards (CHEERS) Checklist
Items to include when reporting economic evaluations of health interventions

Section/Topic	Item No	Recommendation	Reported on page No / Line No
Title and abstract			
Title	1	Identify the study as an economic evaluation or use more specific terms such as "cost-effectiveness analysis", and describe the interventions compared.	**Title page**
Abstract	2	Provide a structured summary of objectives, perspective, setting, methods (including study design and inputs), results (including base case and uncertainty analyses), and conclusions.	**Page 1, lines 1-29**
Introduction			
Background and objectives	3	Provide an explicit statement of the broader context for the study.	**Page 3, lines 46-68**
		Present the study question and its relevance for health policy or practice decisions.	**Page 3, lines 68-71**
Methods			
Target population and subgroups	4	Describe characteristics of the base case population and subgroups analysed, including why they were chosen.	**Page 3, lines 73-80**
Setting and location	5	State relevant aspects of the system(s) in which the decision(s) need(s) to be made.	**Page 3, lines 95-99**
Study perspective	6	Describe the perspective of the study and relate this to the costs being evaluated.	**Page 4, lines 92-99**
Comparators	7	Describe the interventions or strategies being compared and state why they were chosen.	**Page 3, lines 46-60**
Time horizon	8	State the time horizon(s) over which costs and consequences are being evaluated and say why appropriate.	**Page 3, lines 82-83**
Discount rate	9	Report the choice of discount rate(s) used for costs and outcomes and say why appropriate.	**Page 5, lines 137-145**
Choice of health outcomes	10	Describe what outcomes were used as the measure(s) of benefit in the evaluation and their relevance for the type of analysis performed.	**Page 5, lines 141-158**
Measurement of effectiveness	11a	*Single study-based estimates:* Describe fully the design features of the single effectiveness study and why the single study was a sufficient source of clinical effectiveness data.	**Page 4, lines 100-122**
	11b	*Synthesis-based estimates:* Describe fully the methods used for identification of included studies and synthesis of clinical	

		effectiveness data.	
Measurement and valuation of preference-based outcomes	12	If applicable, describe the population and methods used to elicit preferences for outcomes.	**Page 5, lines 140-158**
Estimating resources and costs	13a	*Single study-based economic evaluation:* Describe approaches used to estimate resource use associated with the alternative interventions. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs.	
	13b	*Model-based economic evaluation:* Describe approaches and data sources used to estimate resource use associated with model health states. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs.	**Pages 4-55, lines 123-136**
Currency, price data, and conversion	14	Report the dates of the estimated resource quantities and unit costs. Describe methods for adjusting estimated unit costs to the year of reported costs if necessary. Describe methods for converting costs into a common currency base and the exchange rate.	**Page 5, lines 138-139**
Choice of model	15	Describe and give reasons for the specific type of decision-analytical model used. Providing a figure to show model structure is strongly recommended.	**Pages 3-4, lines 81-91**
Assumptions	16	Describe all structural or other assumptions underpinning the decision-analytical model.	**Pages 4-5, lines 88-91**
Analytic methods	17	Describe all analytical methods supporting the evaluation. This could include methods for dealing with skewed, missing, or censored data; extrapolation methods; methods for pooling data; approaches to validate or make adjustments (such as half cycle corrections) to a model; and methods for handling population heterogeneity and uncertainty.	**Page 5, lines 159-167**
Results			
Study parameters	18	Report the values, ranges, references, and, if used, probability distributions for all parameters. Report reasons or sources for distributions used to represent uncertainty where appropriate. Providing a table to show the input values is strongly recommended.	**Appendix**
Incremental costs and outcomes	19	For each intervention, report mean values for the main categories of estimated costs and outcomes of interest, as well as mean differences between the comparator groups. If applicable, report incremental cost-effectiveness ratios.	**Tables 1 and 3**
Characterizing uncertainty	20a	*Single study-based economic evaluation:* Describe the effects of sampling uncertainty for the estimated incremental cost and incremental effectiveness parameters, together with the impact of methodological assumptions (such as discount rate, study perspective).	

	20b	*Model-based economic evaluation:* Describe the effects on the results of uncertainty for all input parameters, and uncertainty related to the structure of the model and assumptions.	**Tables 1, 2 and 3**
Characterizing heterogeneity	21	If applicable, report differences in costs, outcomes, or cost-effectiveness that can be explained by variations between subgroups of patients with different baseline characteristics or other observed variability in effects that are not reducible by more information.	**Tables 1, 2 and 3**
Discussion			
Study findings, limitations, generalizability, and current knowledge	22	Summarise key study findings and describe how they support the conclusions reached. Discuss limitations and the generalisability of the findings and how the findings fit with current knowledge.	**Pages 6-7, lines 192-253**
Other			
Source of funding	23	Describe how the study was funded and the role of the funder in the identification, design, conduct, and reporting of the analysis. Describe other non-monetary sources of support.	**Page 8, lines 265-267**
Conflicts of interest	24	Describe any potential for conflict of interest of study contributors in accordance with journal policy. In the absence of a journal policy, we recommend authors comply with International Committee of Medical Journal Editors recommendations.	**Page 8, lines 273-277**

BMJ Open

Cost-effectiveness of unicompartmental compared to total knee replacement: a population-based study using data from the National Joint Registry for England and Wales

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2017-020977.R1
Article Type:	Research
Date Submitted by the Author:	06-Mar-2018
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Primary Subject Heading:	Health economics
Secondary Subject Heading:	Surgery
Keywords:	Osteoarthritis, Unicompartmental knee replacement, Total knee replacement, Knee < ORTHOPAEDIC & TRAUMA SURGERY

Cost -effectiveness of unicompartmental compared to total knee replacement: a population-based study using data from the National Joint Registry for England and Wales

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KEYWORDS
Knee; Osteoarthritis; Arthroplasty; Unicompartmental knee replacement; Total knee replacement

ABSTRACT

Objectives

To assess the value for money of unicompartmental knee replacement (UKR) compared to total knee replacement (TKR).

Design

A lifetime Markov model provided the framework for the analysis.

Setting

Data from the National Joint Registry (NJR) for England and Wales primarily informed the analysis.

Participants

Propensity score matched patients in the NJR who received either a UKR or TKR.

Interventions

UKR is a less invasive alternative to TKR, where only the compartment affected by osteoarthritis is replaced.

Primary outcome measures

Incremental Quality-Adjusted Life Years (QALYs) and healthcare system costs.

Results

The provision of UKR is expected to lead to a gain in QALYs compared to TKR for all age and gender subgroups (Male <60: 0.12, 60-75: 0.20, 75+: 0.19, Female <60: 0.10, 60-75: 0.28, 75+: 0.44) and a reduction in costs (Male <60: -£1,223, 60-75: -£1,355, 75+: -£2,005, Female <60: -£601, 60-75: -£935, 75+: -£1,102 per patient over the lifetime). UKR is expected to lead to a reduction in QALYs compared to TKR when performed by surgeons with low UKR utilisation, but an increase among those with high utilisation (<10%, median 6%: -0.04, ≥10%, median 27%: 0.26). Regardless of surgeon usage, costs associated with UKR are expected to be lower than those of TKR (<10%: -£127, ≥10%: -£758).

Conclusions

UKR can be expected to generate better health outcomes and lower lifetime costs than TKR. Surgeon usage of UKR does, however, have a significant impact on the cost-effectiveness of the procedure. To achieve the best results, surgeons need to perform a sufficient proportion of knee replacements as UKR, hence low-usage surgeon may need to broaden their indications of UKR to achieve this.

ARTICLE SUMMARY

Strengths and limitations of this study

- Routinely collected data provided real-world evidence of costs and health outcomes following UKR and TKR.
- Propensity score matching was used to identify comparable individuals who received UKR or TKR.
- Differences between comparator groups may have remained in unobserved characteristics, such as pre-operative radiographs.
- Assumptions were required to extrapolate quality of life and risk of revision over patient lifetimes.

INTRODUCTION

For individuals with end-stage symptomatic osteoarthritis of the knee, total knee replacement (TKR) relieves pain and improves function.[1] In a substantial proportion of cases, by some estimates up to 50%, patients could receive an unicompartmental knee replacement (UKR) instead. UKR is less invasive than TKR, sparing the normal joint surfaces and cruciate ligaments,[2 3] and consequently is associated with a faster recovery and lower risk of post-operative complications and mortality.[4 5] In early and late comparisons of patient-reported outcomes (PROMs), UKR has also been shown to result in superior outcomes overall, with a higher proportion of patients reporting an excellent result.[6 7] However, UKR is also associated with a higher risk of revision than TKR,[4] with this due in large part to a lower threshold for revision.[8]

The choice between UKR and TKR also has economic implications. Given that typical length of stay is lower for UKR,[4] undertaking a UKR can be expected to require fewer healthcare system resources than a TKR. This upfront cost-saving could, however, be offset by the cost of additional reoperations and revisions. Differences in outcomes, in terms of pain and function, may also lead to differences in primary health care utilisation which would further affect the overall costs of the procedures.

The relative merit of each procedure can be expected to vary depending on patient and surgical factors. Outcomes following UKR, in particular, are impacted by surgical factors. Surgeons' caseload (the number of UKR performed) and usage of UKR (the percentage of their primary knee replacements that are UKRs) have been shown to have a substantial impact on the success of UKR with those performed by high usage surgeons expected to have comparable reoperation rates to TKR.[9]

Cost-effectiveness analyses offer a means of reducing decision uncertainty by providing a comparative analysis of both the costs and health outcomes of UKR and TKR. Our aim in this study was to estimate the cost-effectiveness of UKR compared to TKR based on routinely-collected data from the UK and, in particular, to assess how cost-effectiveness varies depending on i) the age and gender of patients, and ii) surgeon usage of UKR.

MATERIALS AND METHODS

Target population and subgroups

The study population for this analysis is comprised of those patients who could receive either a UKR or TKR. We use propensity score matching to identify those patients who received a TKR who were similar in all relevant observable characteristics to patients who received a UKR and assume both groups to be eligible for a UKR but ultimately receiving either a TKR or a UKR. We consider the cost-effectiveness of UKR compared to TKR in terms of six subgroups based on age (<60, 60 to 75, and >75) and gender. In a further analysis, we consider the effect of surgeon 'usage' of UKR on cost-effectiveness for two subgroups (<10% and ≥10%).

Decision model

A lifetime Markov model, shown in Figure 1, provides the framework for the analysis, with patients passing through clinically and economically important health states as time passes.[10] Patients begin by having a primary UKR or TKR, after which they have a revision operation or remain unrevised. After a revision, patients can have a further revision (re-revised) or remain 'revised'. Following a re-revision, patients remain as 're-revised' until death. From all health states patients have a risk of death and the model goes through consecutive cycles until all patients have died. Patients can transition between states on a yearly basis. The key simplifying assumptions of the model are that patients can have only two revisions and that only one revision can occur in a year. While

reoperations are not incorporated as a model state, their likelihood and costs are incorporated into the unrevised state.

Study perspective

This evaluation has been undertaken from a healthcare system perspective, hence only the costs incurred by the health system are included. These costs relate to surgical procedures being undertaken and primary care utilisation by patients. For health care interventions to be considered cost-effective (i.e. providing sufficient value for money to merit their provision) in England they should have an incremental cost per additional quality-adjusted life year (QALY) of less than £20,000 to £30,000.[11] For this analysis the cost-effectiveness of UKR is considered at the lower threshold of £20,000.

Measurement of effectiveness

An extract of data from the National Joint Registry (NJR) for England and Wales linked to the Hospital Episode Statistics (HES) database and the Office for National Statistics (ONS) informed estimates of the effectiveness of UKR and TKR. This data were previously used to compare adverse events following the procedures, with propensity scores used to match 25,334 UKRs to 75,996 comparable TKRs who received their primary procedure between 2003 and 2012.[9] These same matched patients were split into the age and gender subgroups for this analysis. As surgeon usage of UKR was not a variable in the original propensity score matching, matching was re-run to achieve balance within usage subgroups (see Appendix). This ensured that the comparator groups, UKR performed by surgeons with usage under 10% against TKR, and UKR by surgeons with usage equal to or over 10% against TKR, were balanced in their observable characteristics.

Parametric models were specified independently for each treatment subgroup to estimate the risk of revision and death. For the base case analysis, the Weibull distribution was used for both. The risk of revision was extrapolated using estimates from the models, and risk of death was assumed to return to that given by age- and gender-specific UK life tables after the period of follow up.[12] Sensitivity analyses were performed for the risk of revision with the analysis re-run using the log-normal and exponential distributions instead of the Weibull. Further details of the estimated parametric models are provided in the Appendix.

Risk of re-revision was based on evidence from the NJR which reported that in the first year following a revision patients have a 2.7% probability of a re-revision, and a 1.4% chance in subsequent years.[13] With risk of re-revision being similar following a revision of UKR and TKR,[14] these risks were applied in the same manner for both procedures. Risk of mortality following a revision and re-revision was assumed to be equal to that of those unrevised.

Estimating resource use and costs

The hospital costs associated with the primary procedures and revisions were based on patients' Healthcare Resource Group (HRG) codes (which classify episodes with similar levels of resource consumption into the same group) and length of stay, with costs estimated using the 2014/15 National Tariff Payment System.[15] In addition, the costs of any implant-retaining reoperations over the five years following each surgery were also incorporated. We assumed the cost of a re-revision was the same as a revision in the base case analysis. The effect of this assumption on the results was tested by re-running the analysis with a re-revision expected to have a cost 50% higher than that of a revision.

For primary care costs an extract of the Clinical Practice Research Datalink (CPRD) was used where 335 UKRs were matched with 1,005 TKRs based on propensity scores. These patients and their costs

are summarised in the Appendix. The choice of procedure was found to have no significant effect on resource use and so the costs of treatment groups were pooled and single estimates extracted for each age and gender subgroup.

Future costs and health outcomes were discounted by an annual rate of 3.5%, in line with guidelines for England and Wales.[16] Costs are in British pounds, in 2014 prices. Estimated hospital and primary care costs are detailed in the Appendix.

Measurement and valuation of preference-based outcomes

As patient-reported outcome measures (PROMs) have only been collected since 2009, a separate propensity score matched cohort of 3,519 UKRs and 10,557 TKRs for whom these data were available were used to inform estimates of health-related quality of life for each subgroup considered. Again, these patients and the process of matching have been previously described in detail,[6] and matching was re-run for usage subgroups (see Appendix). EuroQol 5D (EQ-5D) is a generic measure of health-related quality of life, which ranges from -0.59 (worst) to 1 (best), with 0 representing death and 0.074 considered a minimally important difference.[17]

In the year following a primary, patients were expected to steadily progress from their pre-operative score to their post-operative score at six months, at which they would remain for the rest of year. As EQ-5D following UKR and TKR remains stable over ten years following surgery for those who remain unrevised,[7] in the absence of any further procedure those unrevised were expected to remain at their post-operative score. The trajectory of quality of life following revision was assumed to be similar to primary procedures, with patients expected to progress from their pre-operative score to their post-operative score over six months, at which point they were expected to remain unless they went on to have a re-revision. However, due to the small number of individuals with a revision and scores available, subgroups were pooled for revision parameters. We assumed quality-of-life for a re-revision would fall in the same proportion as they did from primary to a revision procedure. To test the impact of this assumption, we conducted a sensitivity analysis where the quality of life for a re-revision was assumed instead to remain equal to that of revision. Estimates of health-related quality-of-life were based on EQ-5D collected prior to and six-month following surgery (see Appendix).

Analytic methods

Expected (mean) costs and QALYs were estimated for each subgroup receiving either UKR or TKR. The resulting incremental cost-effectiveness ratio (ICER) was then calculated (equal to the difference in costs divided by the difference in QALYs), with an intervention being considered dominant if it both reduced costs and increased QALYs.[18] The effect of parameter uncertainty was assessed using probabilistic sensitivity analysis, with input parameters assigned from probability distributions and 1,000 Monte Carlo simulations conducted for each subgroup. Probability distributions were based on the type of data, with gamma distributions used for costs as well as pre-operative quality of life so as to allow values below zero, beta distributions used for post-operative quality of life, and normal distributions used for the coefficients of parametric models and age.[19 20] The sets of estimated costs and QALYs from each of 1,000 Monte Carlo simulations are presented, alongside the expected results, on a cost-effectiveness plane.

Patient and public involvement

No patients were involved in the development of the research question or the outcome measures nor the design of the study. There are no plans to disseminate the results of the research to study participants.

RESULTS

Compared to TKR, UKR was found to be associated with a greater likelihood of revision over individuals remaining lifetimes for each of the subgroups. UKR was, however, associated with better post-operative quality of life following the primary procedure than TKR for all age and gender subgroups, with the difference most pronounced for older patients. Moreover, those undergoing revision following UKR had better quality of life prior to and following revision than those who had TKR. For all subgroups, the hospital costs of primary and revision surgery were lower for UKR than TKR. See Appendix for further details.

UKR was found to be cost-saving and health improving compared to TKR for all age and gender subgroups, making UKR the dominant treatment choice for those individuals eligible for either procedure (see Table 1). The largest expected savings were for males over 75 while the biggest improvement in quality of life was for females over 75. For those aged over 60 years of age, parameter uncertainty had little effect on the conclusion that UKR was cost-effective. However, for those under 60 there was some uncertainty, with a 13% and 28% probability that TKR was cost-effective for males and females under 60, respectively. Figure 2 presents the estimated mean and probabilistic sets of incremental costs and QALYs associated with the provision of UKR rather than TKR for each age and gender subgroup. These findings were broadly robust to changes in modelling assumptions (see Table 2 and Appendix for full results from each scenario analysis).

When UKR was performed by surgeons with a usage of the procedure equal to or above 10% (median usage was 27%), UKR was found to be unequivocally cost-saving and health improving compared to TKR, as shown in Table 3. When performed by surgeons with usage of less than 10% (median usage was 6%), however, UKR no longer led to better health outcomes than TKR and TKR was the cost-effective procedure. Figure 3 presents the estimated means and sets of costs and QALYs for both usage subgroups.

DISCUSSION

Principal findings

For patients who are eligible for either procedure, the provision of UKR rather than TKR has been estimated to lead to a gain in QALYs and a reduction in costs for all age and gender subgroups. There is little uncertainty around this conclusion for older patients. Such patients have, given their lower life expectancy, a lower lifetime risk of revision and report greater improvements in post-operative quality of life compared to TKR than younger patients. Significant uncertainty does surround whether UKR would be health-improving for younger patients for whom even relatively small differences in annual revision rates lead to substantial differences in lifetime revision rates.

Surgeon usage of UKR, i.e. the percentage of the knee replacements they perform that were UKRs, had a significant impact on the cost-effectiveness of the procedure. UKR was expected to be cost-effective when compared to TKR with 100% probability (given parameter uncertainty) when performed by surgeons with usage at or above 10%, with these surgeons having a median usage of 27%. However, when UKR performed by low usage surgeons were compared against TKR, TKR was the cost-effective option.

Limitations of the study

Our analysis was based on routinely-collected data from the NHS in England and Wales. While this dataset has the advantage of providing real-world evidence for costs and health outcomes following UKR and TKR, it also has the potential pitfalls of any such observational data. In particular, confounding by indication can be expected with treatment selection based on patient and surgical characteristics. Propensity score matching was used to achieve balance in a wide range of observed

characteristics, however imbalances may still exist in unobserved factors which could bias the findings of the study. In particular, it was not possible to include pre-operative radiographs, which would provide a better assessment of patients eligible to have either procedure, hence differences in these may have persisted between matched groups.

With costs and health outcomes estimated over the remaining lifetimes of patients, modelling assumptions were unavoidable. Individuals' risk of revision over their remaining lifetimes were based on observed revisions over the eight years following surgery. In addition, quality of life estimates were based on scores recorded prior to and six months following primary and revision procedures and we assumed that, in the absence of further procedures, individuals would remain at their post-operative scores into the future. This assumption appears to be plausible following primary procedures,[7] however it is uncertain whether a similar pattern would be seen following revisions. If quality of life following revision steadily returned to comparable levels observed after primary procedures, the cost-effectiveness of UKR, which has a higher risk of revision, will have been somewhat underestimated. Furthermore, we assumed quality of life associated with re-revision would have dropped by the same proportion as that observed from primary to revision and the cost of a re-revision was assumed to be equivalent to that of a revision. These assumptions were necessarily subjective; however, scenario analyses showed the findings of the study to be robust to changes in these assumptions.

Study findings in context

In line with findings from previous economic evaluations of UKR and TKR,[21] in this study we found UKR to be less costly than TKR.[7] Furthermore, consistent with previous research, UKR was also found to lead to better health outcomes for patients aged 65 and over. Little uncertainty surrounds this conclusion for older patients, who benefit most from a less-invasive procedure and have a low lifetime risk of revision. For younger patients, whose health outcomes are mixed,[22-24] this analysis found that UKR was also expected to lead to better health outcomes than TKR, although there was significant uncertainty in this conclusion. The variation in findings for younger patients across studies appears to be driven by differences in estimates for both the risk of revision and the expected effect of revision on quality of life.[7]

This study has also highlighted the importance of surgeon usage of UKR on the cost-effectiveness of the procedure. In the high usage group, with a median usage of 27%, UKR was found, with no parameter uncertainly, to lead to better health outcomes and to cost-savings compared to TKR. In contrast, in the low usage group UKR provided worse health outcomes and only small cost savings. High usage surgeons appear to achieve good results following UKR regardless of their caseload of the procedure, and so the poor results of those with low usage appear to be primarily due to inappropriate patient selection.[25] In particular, low usage surgeons seem more likely to offer UKR to patients with partial-thickness cartilage loss (PTCL). PTCL is associated with poor outcomes following UKR and so it has been recommended that UKR should only be undertaken for individuals with bone-on-bone arthritis.[9] High usage surgeons, therefore, should be supported while low usage surgeons should consider changing their practice. If surgeons with low or no usage of UKR learnt and applied the indications and techniques of current high usage surgeons, they can be expected to achieve similar results.

CONCLUSIONS

For those patients with appropriate indications, UKR provides an alternative to TKR which is less costly for the healthcare system to provide and leads to greater improvements in their overall health outcomes over their lifetime. If surgeons performing UKR achieved sufficient usage of the

procedure, future economic and population health gains would likely be increased even further. Additional work is needed to identify the optimal usage of UKR, which may depend on the type of implants used. Surgeons should not have a low usage and be performing UKR in less than 10% of their knee replacements. The median usage in the high usage group was 27% so it would be reasonable for surgeons to aim for a quarter of their knee replacements to be UKR. However it has been shown that up to 50% of replacements could be UKR, so the optimal usage may be higher.[26]

ACKNOWLEDGMENTS

We thank the patients and staff of all the hospitals in England and Wales who have contributed data to the National Joint Registry; and the Healthcare Quality Improvement Partnership (HQIP), the NJR Steering Committee, and staff at the NJR Centre for facilitating this work. The authors have conformed to the NJR's standard protocol for data access and publication. The views expressed represent those of the authors and do not necessarily reflect those of the National Joint Registry Steering Committee or the Healthcare Quality Improvement Partnership (HQIP) who do not vouch for how the information is presented. HES data copyright © 2013, Re-used with the permission of the Health & Social Care Information Centre. All rights reserved.

FUNDING

This research was supported by funding from Zimmer Biomet. Zimmer Biomet had no other role in the design or conduct of the study.

CONTRIBUTORS

EB, ADL, TWH, AJ, HGP, DWM and RPV all made substantial contributions to conception and design of the study. EB, ADL and RPV undertook the statistical analysis. EB, DWM and RPV drafted the manuscript with ADL, TWH, AJ and HGP revising it for important intellectual content. All authors read and approved the final manuscript.

COMPETING INTERESTS

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: financial support for the submitted work from Zimmer Biomet; HGP and DWM have received consultancy fees and DWM has received royalties from Zimmer Biomet; TWH and DWM hold various patents related to Total and Unicompartmental Knee Replacement.

ETHICAL APPROVAL

Permission to access data was given by the National Information Governance Board, now the Confidentiality Advisory Group (application number ECC 1-02 (FT3)/2013).

DATA SHARING

Access to data is available from the National Joint Registry for England and Wales.

REFERENCES

1. Carr AJ, Robertsson O, Graves S, et al. Knee replacement. *The Lancet* 2012;379(9823):1331-40. doi: 10.1016/s0140-6736(11)60752-6
2. Ashraf ST, Ackroyd CE, Newman JH. Compartmental knee arthroplasty. *Current Orthopaedics* 2003;17(2):134-43. doi: 10.1054/cuor.2002.0312
3. Lutzner J, Kasten P, Gunther KP, et al. Surgical options for patients with osteoarthritis of the knee. *Nat Rev Rheumatol* 2009;5(6):309-16. doi: 10.1038/nrrheum.2009.88
4. Liddle AD, Judge A, Pandit H, et al. 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. *The Lancet* 2014;384(9952):1437-45. doi: 10.1016/s0140-6736(14)60419-0
5. Hunt LP, Ben-Shlomo Y, Clark EM, et al. 45-day mortality after 467 779 knee replacements for osteoarthritis from the National Joint Registry for England and Wales: an observational study. *The Lancet* 2014;384(9952):1429-36. doi: 10.1016/s0140-6736(14)60540-7
6. Liddle AD, Pandit H, Judge A, et al. Patient-reported outcomes after total and unicompartmental knee arthroplasty: a study of 14,076 matched patients from the National Joint Registry for England and Wales. *Bone Joint J* 2015;97-B(6):793-801. doi: 10.1302/0301-620X.97B6.35155
7. Burn E, Sanchez-Santos MT, Pandit HG, et al. Ten-year patient-reported outcomes following total and minimally invasive unicompartmental knee arthroplasty: a propensity score-matched cohort analysis. *Knee Surg Sports Traumatol Arthrosc* 2016 doi: 10.1007/s00167-016-4404-7
8. Goodfellow JW, O'Connor JJ, Murray DW. A critique of revision rate as an outcome measure: re-interpretation of knee joint registry data. *J Bone Joint Surg Br* 2010;92(12):1628-31. doi: 10.1302/0301-620X.92B12.25193
9. Liddle AD, Pandit H, Judge A, et al. Optimal usage of unicompartmental knee arthroplasty: a study of 41 986 cases from the National Joint Registry for England and Wales. *Bone Joint J* 2015;97-B(11):1506-11. doi: 10.1302/0301-620X.97B11.35551
10. Briggs A, Sculpher M. An introduction to Markov modelling for economic evaluation. *Pharmacoeconomics* 1998;13(4):397-409.
11. McCabe C, Claxton K, Culyer AJ. The NICE cost-effectiveness threshold - What it is and what that means. *Pharmacoeconomics* 2008;26(9):733-44. doi: Doi 10.2165/00019053-200826090-00004
12. ONS. National Life Tables: United Kingdom. https://www.ons.gov.uk/, 2016.
13. National Joint Registry for England W, Northern Ireland and the Isle of Man. 13th annual report, 2016.
14. Leta TH, Lygre SH, Skredderstuen A, et al. Outcomes of Unicompartmental Knee Arthroplasty After Aseptic Revision to Total Knee Arthroplasty: A Comparative Study of 768 TKAs and 578 UKAs Revised to TKAs from the Norwegian Arthroplasty Register (1994 to 2011). *The Journal of bone and joint surgery American volume* 2016;98(6):431-40. doi: 10.2106/JBJS.O.00499
15. Monitor and NHS England. National tariff payment system 2014/15. https://www.gov.uk/government/publications/national-tariff-payment-system-2014-to-2015, 2013.
16. NICE. Guide to the methods of technology appraisal 2013. 2013
17. Walters SJ, Brazier JE. Comparison of the minimally important difference for two health state utility measures: EQ-5D and SF-6D. *Quality of Life Research* 2005;14(6):1523-32. doi: 10.1007/s11136-004-7713-0
18. Drummond M, McGuire A. Economic Evaluation in Health Care: Merging theory with practice. New York: Oxford University Press 2001.
19. Briggs A, Sculpher M, Claxton K. Decision Modelling for Health Economic Evaluation: Oxford University Press 2006.

20. Edlin R, McCabe C, Hulme C, et al. Cost effectiveness modelling for health technology assessment. A practical course: Adis 2015.
21. Burn E, Liddle AD, Hamilton TW, et al. Choosing Between Unicompartmental and Total Knee Replacement: What Can Economic Evaluations Tell Us? A Systematic Review. *PharmacoEconomics - Open* 2017 doi: 10.1007/s41669-017-0017-4
22. Peersman G, Jak W, Vandenlangenbergh T, et al. Cost-effectiveness of unicondylar versus total knee arthroplasty: a Markov model analysis. *The Knee* 2014;21:S37-S42. doi: 10.1016/s0968-0160(14)50008-7
23. Konopka JF, Gomoll AH, Thornhill TS, et al. The cost-effectiveness of surgical treatment of medial unicompartmental knee osteoarthritis in younger patients: a computer model-based evaluation. *The Journal of bone and joint surgery American volume* 2015;97(10):807-17. doi: 10.2106/JBJS.N.00925
24. Ghomrawi HM, Eggman AA, Pearle AD. Effect of age on cost-effectiveness of unicompartmental knee arthroplasty compared with total knee arthroplasty in the U.S. *The Journal of bone and joint surgery American volume* 2015;97(5):396-402. doi: 10.2106/JBJS.N.00169
25. Hamilton TW, Rizkalla JM, Kontochristos L, et al. The Interaction of Caseload and Usage in Determining Outcomes of Unicompartmental Knee Arthroplasty: A Meta-Analysis. *J Arthroplasty* 2017;32(10):3228-37 e2. doi: 10.1016/j.arth.2017.04.063
26. Willis-Owen CA, Brust K, Alsop H, et al. Unicondylar knee arthroplasty in the UK National Health Service: an analysis of candidacy, outcome and cost efficacy. *The Knee* 2009;16(6):473-8. doi: 10.1016/j.knee.2009.04.006

TABLE 1: BASE CASE COST-EFFECTIVENESS RESULTS FOR AGE AND GENDER SUBGROUPS

	TKR		UKR				
	QALYs	Costs (£)	QALYs	Costs (£)	Δ QALYs	Δ Costs (£)	ICER (probability cost-effective*)
Male, <60	10.28 (10.07 to 10.47)	15,357 (14,704 to 16,019)	10.39 (10.11 to 10.70)	14,134 (13,489 to 14,810)	0.12 (-0.19 to 0.47)	-1,223 (-1,439 to -1,014)	UKR dominant (87%)
Male, 60-75	8.61 (8.50 to 8.70)	13,307 (12,584 to 14,037)	8.81 (8.63 to 8.97)	11,952 (11,246 to 12,704)	0.20 (0.01 to 0.39)	-1,355 (-1,610 to -1,122)	UKR dominant (100%)
Male, 75+	5.61 (5.49 to 5.73)	11,454 (10,506 to 12,511)	5.80 (5.64 to 5.97)	9,450 (8,442 to 10,631)	0.19 (0.02 to 0.37)	-2,005 (-2,361 to -1,521)	UKR dominant (100%)
Female, <60	10.68 (10.50 to 10.89)	16,961 (16,101 to 17,899)	10.78 (10.42 to 11.09)	16,360 (15,514 to 17,273)	0.10 (-0.33 to 0.47)	-601 (-887 to -350)	UKR dominant (72%)
Female, 60-75	8.96 (8.84 to 9.06)	13,814 (13,089 to 14,602)	9.24 (9.04 to 9.43)	12,878 (12,068 to 13,702)	0.28 (0.05 to 0.50)	-935 (-1,186 to -710)	UKR dominant (100%)
Female, 75+	6.02 (5.82 to 6.15)	11,410 (10,541 to 12,378)	6.46 (6.20 to 6.69)	10,308 (9,312 to 11,378)	0.44 (0.18 to 0.71)	-1,102 (-1,646 to -695)	UKR dominant (100%)

Expected (mean) values with 95% confidence intervals in parentheses. UKR is considered 'dominant' if it is expected to improve health outcomes and reduce health care costs. *Given a cost-effectiveness threshold of £20,000. ICER: incremental cost-effectiveness ratio.

TABLE 2: SCENARIO ANALYSES

	Age and gender subgroups					
	Male, <60	**Male, 60-75**	**Male, 75+**	**Female, <60**	**Female, 60-75**	**Female, 75+**
Base case assumptions	UKR dominant (87%)	UKR dominant (100%)	UKR dominant (100%)	UKR dominant (72%)	UKR dominant (100%)	UKR dominant (100%)
Distribution of parametric model for revision risk						
Exponential	UKR dominant (92%)	UKR dominant (100%)	UKR dominant (100%)	UKR dominant (78%)	UKR dominant (100%)	UKR dominant (100%)
Log-normal	UKR dominant (89%)	UKR dominant (100%)	UKR dominant (100%)	UKR dominant (77%)	UKR dominant (100%)	UKR dominant (100%)
Health utility						
Re-revision equal to revision	UKR dominant (95%)	UKR dominant (100%)	UKR dominant (100%)	UKR dominant (91%)	UKR dominant (100%)	UKR dominant (100%)
Cost						
Cost of re-revision 50% higher than revision	UKR dominant (83%)	UKR dominant (100%)	UKR dominant (100%)	UKR dominant (73%)	UKR dominant (100%)	UKR dominant (100%)

Incremental cost-effectiveness ratio (ICER) with probability of being cost-effective, based on probabilistic sensitivity analysis and given a cost-effectiveness threshold of £20,000, in parentheses. UKR is considered 'dominant' if it is expected to improve health outcomes and reduce health care costs. Full results for each scenario analysis are detailed in the Appendix.

TABLE 3: BASE CASE COST-EFFECTIVENESS RESULTS FOR USAGE OF UKR SUBGROUPS

	TKR		UKR				
	QALYs	Costs (£)	QALYs	Costs (£)	Δ QALYs	Δ Costs (£)	ICER (probability cost-effective*)
UKR <10%	8.67 (8.53 to 8.80)	13,267 (12,834 to 13,731)	8.62 (8.38 to 8.84)	13,140 (12,643 to 13,614)	-0.04 (-0.32 to 0.21)	-127 (-429 to 127)	£3,000/QALY (37%)
UKR ≥10%	8.81 (8.73 to 8.88)	13,170 (12,726 to 13,614)	9.06 (8.94 to 9.18)	12,411 (11,978 to 12,856)	0.26 (0.12 to 0.40)	-758 (-939 to -579)	UKR dominant (100%)

Expected (mean) values with 95% confidence intervals in parentheses. UKR is considered 'dominant' if it is expected to improve health outcomes and reduce health care costs. *Given a cost-effectiveness threshold of £20,000.

Figure 1: Model outline. The decision-analytic model provides the framework for the analysis.

Figure 2: Cost-effectiveness plane for age and gender subgroups. The sets of estimated incremental costs and QALYs associated with the provision of UKR rather than TKR from each of the Monte Carlo simulations are shown as points with the expected results as triangles.

Figure 3: Cost-effectiveness plane for usage subgroups. The sets of estimated incremental costs and QALYs associated with the provision of UKR rather than TKR from each of the Monte Carlo simulations are shown as points with the expected results as triangles.

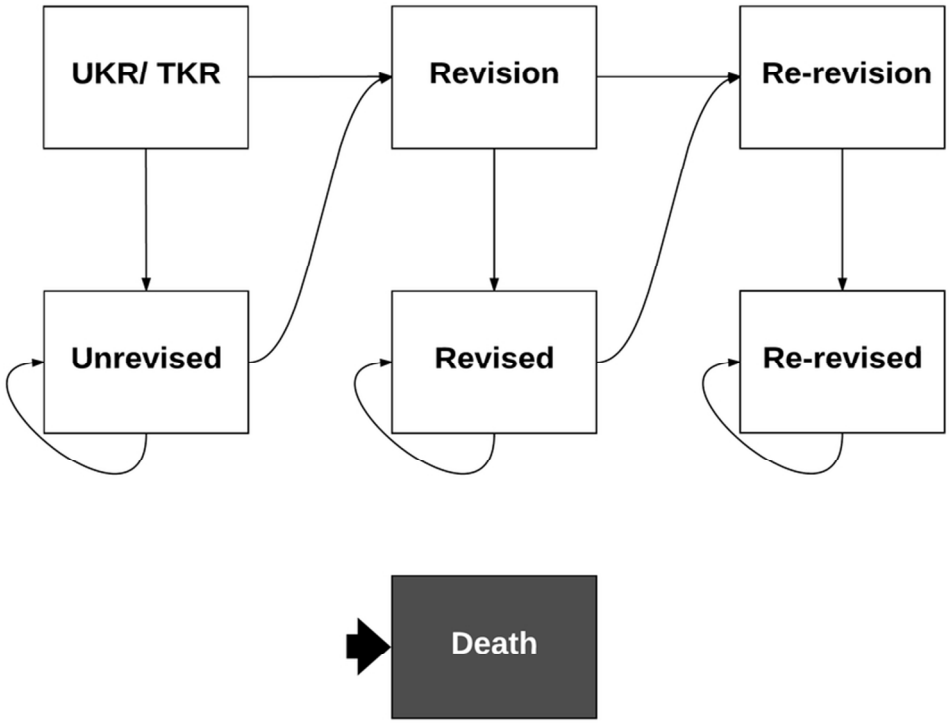

Figure 1: Model outline. The decision-analytic model provides the framework for the analysis.

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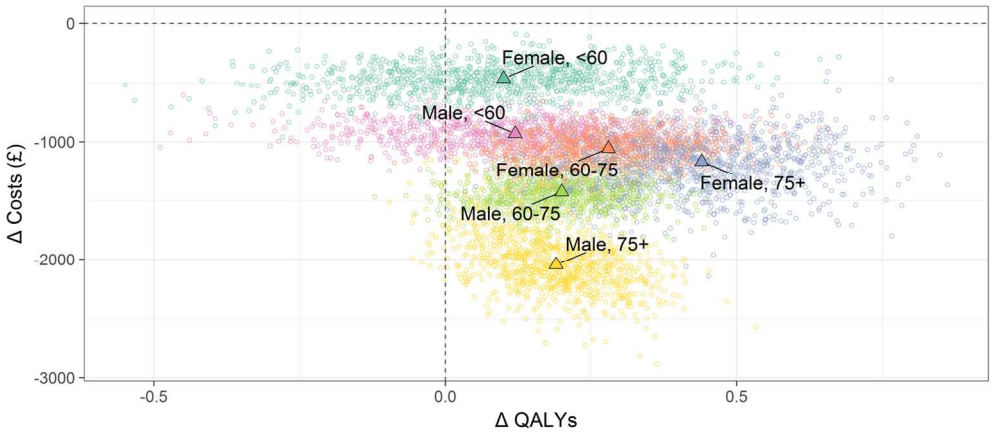
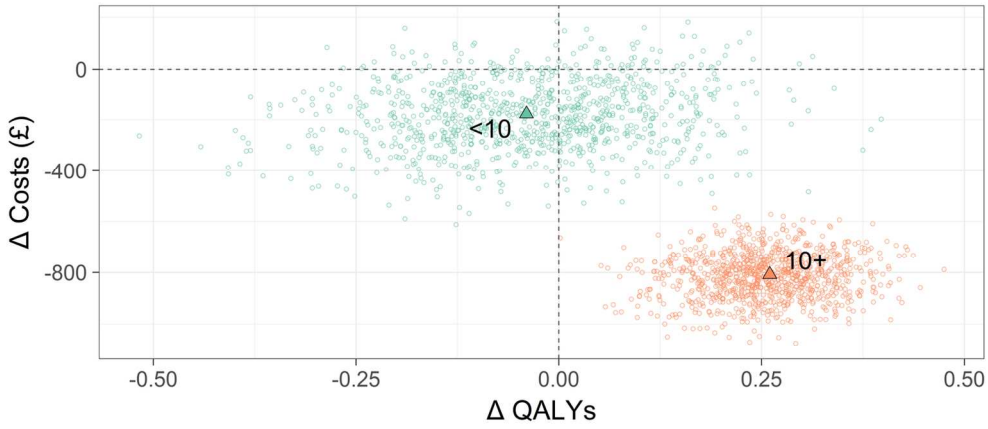


Cost-effectiveness plane for age and gender subgroups. The sets of estimated incremental costs and QALYs associated with the provision of UKR rather than TKR from each of the Monte Carlo simulations are shown as points with the expected results as triangles.

139x61mm (300 x 300 DPI)



Cost-effectiveness plane for usage subgroups. The sets of estimated incremental costs and QALYs associated with the provision of UKR rather than TKR from each of the Monte Carlo simulations are shown as points with the expected results as triangles.

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APPENDIX

PATIENT COUNTS FOR EACH SUBGROUP

Table A1.1: Patient counts for each subgroup

	NJR-HES		HES-PROMs		CPRD
	TKR	UKR	TKR	UKR	All
Age and gender subgroups					
Male, <60	11156	3677	1487	473	82
Male, 60-75	11616	4268	3456	1155	175
Male, 75+	22979	7468	641	241	57
Female, <60	19320	6118	1613	592	54
Female, 60-75	5305	1914	2850	882	164
Female, 75+	5371	1805	510	176	62
Usage subgroups					
UKR <10%	13690	4564	2052	684	-
UKR 10+%	60544	20682	8379	2793	-

NJR linked to HES was used to estimate initial transition probabilities and hospital costs. HES-PROMs was used to estimate quality of life following primary procedure. CPRD was used to estimate primary care costs.

PROPENSITY SCORE MATCHING FOR USAGE SUBGROUPS

Table A2.1 Patient characteristics before and after matching low usage UKRs (<10%) with TKRs for transition probabilities and hospital costs

	Before matching			After matching		
	TKR	UKR (usage <10%)	SMD	TKR	UKR (usage <10%)	SMD
Number of patients	75753	4564		13690	4564	
Age at surgery (mean (sd))	64.72 (9.30)	62.42 (9.11)	0.25	62.54 (9.40)	62.42 (9.11)	0.014
Unit type (%)			0.133			0.001
Public hospital	63990 (84.5)	4011 (87.9)		12030 (87.9)	4011 (87.9)	
Independent hospital	9098 (12.0)	480 (10.5)		1443 (10.5)	480 (10.5)	
Independent sector treatment centre	2665 (3.5)	73 (1.6)		217 (1.6)	73 (1.6)	
Thromboprophylaxis						
Drugs (%)			0.081			0.013
Aspirin	9498 (12.5)	487 (10.7)		1472 (10.8)	487 (10.7)	
Direct thrombin inhibitor	2622 (3.5)	161 (3.5)		458 (3.3)	161 (3.5)	
Unfractionated or low molecular weight heparin	397 (0.5)	21 (0.5)		59 (0.4)	21 (0.5)	
None/Unspecified	9325 (12.3)	606 (13.3)		1847 (13.5)	606 (13.3)	
Other	53187 (70.2)	3265 (71.5)		9786 (71.5)	3265 (71.5)	
Warfarin	724 (1.0)	24 (0.5)		68 (0.5)	24 (0.5)	
Mechanical (%)			0.053			0.022
None/Unspecified	9034 (11.9)	604 (13.2)		1767 (12.9)	604 (13.2)	
Foot pumps	7474 (9.9)	458 (10.0)		1359 (9.9)	458 (10.0)	
Intermittent calf compression	9166 (12.1)	508 (11.1)		1465 (10.7)	508 (11.1)	
Thromboembolic deterrent stockings	49069 (64.8)	2920 (64.0)		8856 (64.7)	2920 (64.0)	
Other	1010 (1.3)	74 (1.6)		243 (1.8)	74 (1.6)	
Gender (%)			0.017			0.016
M	39440 (52.1)	2403 (52.7)		7318 (53.5)	2403 (52.7)	
American Society of Anesthesiologists score (%)			0.104			0.024
1	16018 (21.1)	1152 (25.2)		3568 (26.1)	1152 (25.2)	
2	53087 (70.1)	3077 (67.4)		9181 (67.1)	3077 (67.4)	

3+	6648 (8.8)	335 (7.3)		941 (6.9)	335 (7.3)	
Comorbidities (Charlson index) (%)			0.028			0.009
None	60768 (80.2)	3681 (80.7)		11013 (80.4)	3681 (80.7)	
Mild	12511 (16.5)	755 (16.5)		2303 (16.8)	755 (16.5)	
Moderate	1967 (2.6)	99 (2.2)		291 (2.1)	99 (2.2)	
Severe	507 (0.7)	29 (0.6)		83 (0.6)	29 (0.6)	
Hypertension (mean (sd))	0.35 (0.48)	0.31 (0.46)	0.084	0.30 (0.46)	0.31 (0.46)	0.014
Ethnicity (%)			0.083			0.034
Undefined	9958 (13.1)	640 (14.0)		1933 (14.1)	640 (14.0)	
British (White)	61524 (81.2)	3661 (80.2)		10946 (80.0)	3661 (80.2)	
Irish (White)	411 (0.5)	32 (0.7)		103 (0.8)	32 (0.7)	
Any other White background	1401 (1.8)	101 (2.2)		323 (2.4)	101 (2.2)	
White and Black Caribbean (Mixed)	29 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
White and Black African (Mixed)	11 (0.0)	1 (0.0)		4 (0.0)	1 (0.0)	
White and Asian (Mixed)	42 (0.1)	7 (0.2)		14 (0.1)	7 (0.2)	
Any other Mixed background	31 (0.0)	1 (0.0)		7 (0.1)	1 (0.0)	
Indian (Asian or Asian British)	1068 (1.4)	47 (1.0)		151 (1.1)	47 (1.0)	
Pakistani (Asian or Asian British)	351 (0.5)	11 (0.2)		32 (0.2)	11 (0.2)	
Bangladeshi (Asian or Asian British)	26 (0.0)	1 (0.0)		3 (0.0)	1 (0.0)	
Any other Asian background	195 (0.3)	12 (0.3)		33 (0.2)	12 (0.3)	
Caribbean (Black or Black British)	259 (0.3)	17 (0.4)		54 (0.4)	17 (0.4)	
African (Black or Black British)	146 (0.2)	11 (0.2)		31 (0.2)	11 (0.2)	
Any other Black background	64 (0.1)	4 (0.1)		15 (0.1)	4 (0.1)	
Chinese (other ethnic group)	25 (0.0)	4 (0.1)		6 (0.0)	4 (0.1)	
Any other ethnic group	212 (0.3)	14 (0.3)		35 (0.3)	14 (0.3)	
IMD decile (mean (sd))	6.25 (2.67)	6.08 (2.71)	0.062	6.12 (2.70)	6.08 (2.71)	0.015
Fixation (%)			0.135			0.014
Cementless	5677 (7.5)	200 (4.4)		636 (4.6)	200 (4.4)	
Cemented	68544 (90.5)	4287 (93.9)		12814 (93.6)	4287 (93.9)	
Hybrid	1532 (2.0)	77 (1.7)		240 (1.8)	77 (1.7)	
Cases per consultant per year (mean (sd))	84.74 (58.78)	82.14 (56.83)	0.045	81.49 (56.53)	82.14 (56.83)	0.012

Table A2.2 Patient characteristics before and after matching low usage UKRs (<10%) with TKRs for quality of life

	Before matching			After matching		
	TKR	UKR (usage <10%)	SMD	TKR	UKR (usage <10%)	SMD
Number of patients	10441	684		2052	684	
Age at surgery (mean (sd))	64.38 (8.60)	61.96 (8.58)	0.281	62.19 (8.68)	61.96 (8.58)	0.027
Unit type (%)			0.108			0.006
Public hospital	7726 (74.0)	535 (78.2)		1601 (78.0)	535 (78.2)	
Independent hospital	2267 (21.7)	129 (18.9)		389 (19.0)	129 (18.9)	
Independent sector treatment centre	448 (4.3)	20 (2.9)		62 (3.0)	20 (2.9)	
Thromboprophylaxis						
Drugs (%)			0.029			0.028
Aspirin	2065 (19.8)	134 (19.6)		421 (20.5)	134 (19.6)	
Unfractionated or low molecular weight heparin	203 (1.9)	11 (1.6)		30 (1.5)	11 (1.6)	
None/Unspecified	2171 (20.8)	144 (21.1)		419 (20.4)	144 (21.1)	
Other	5908 (56.6)	388 (56.7)		1162 (56.6)	388 (56.7)	
Warfarin	94 (0.9)	7 (1.0)		20 (1.0)	7 (1.0)	
Mechanical (%)			0.091			0.024
None/Unspecified	2428 (23.3)	151 (22.1)		451 (22.0)	151 (22.1)	
Foot Pumps	887 (8.5)	69 (10.1)		213 (10.4)	69 (10.1)	
Intermittent calf compression	845 (8.1)	43 (6.3)		118 (5.8)	43 (6.3)	
Thromboembolic deterrent stockings	6154 (58.9)	412 (60.2)		1242 (60.5)	412 (60.2)	
Other	127 (1.2)	9 (1.3)		28 (1.4)	9 (1.3)	
Gender (%)			0.021			0.007
M	5511 (52.8)	354 (51.8)		1055 (51.4)	354 (51.8)	
American Society of Anesthesiologists score (%)			0.083			0.065
1	2183 (20.9)	154 (22.5)		431 (21.0)	154 (22.5)	

2	7585 (72.6)	474 (69.3)		1479 (72.1)	474 (69.3)	
3+	673 (6.4)	56 (8.2)		142 (6.9)	56 (8.2)	
Comorbidities (Charlson index) (%)			0.054			0.026
None	8622 (82.6)	564 (82.5)		1685 (82.1)	564 (82.5)	
Mild	1496 (14.3)	103 (15.1)		313 (15.3)	103 (15.1)	
Moderate	240 (2.3)	11 (1.6)		31 (1.5)	11 (1.6)	
Severe	83 (0.8)	6 (0.9)		23 (1.1)	6 (0.9)	
Hypertension (mean (sd))	0.35 (0.48)	0.36 (0.48)	0.025	0.35 (0.48)	0.36 (0.48)	0.017
Ethnicity (%)			0.099			0.073
Undefined	2253 (21.6)	148 (21.6)		470 (22.9)	148 (21.6)	
British (White)	7643 (73.2)	505 (73.8)		1494 (72.8)	505 (73.8)	
Irish (White)	52 (0.5)	4 (0.6)		15 (0.7)	4 (0.6)	
Any other White background	225 (2.2)	14 (2.0)		43 (2.1)	14 (2.0)	
White and Black Caribbean (Mixed)	7 (0.1)	0 (0.0)		0 (0.0)	0 (0.0)	
White and Black African (Mixed)	0 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
White and Asian (Mixed)	1 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
Any other Mixed background	1 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
Indian (Asian or Asian British)	114 (1.1)	7 (1.0)		22 (1.1)	7 (1.0)	
Pakistani (Asian or Asian British)	34 (0.3)	1 (0.1)		1 (0.0)	1 (0.1)	
Bangladeshi (Asian or Asian British)	6 (0.1)	0 (0.0)		0 (0.0)	0 (0.0)	
Any other Asian background	10 (0.1)	1 (0.1)		1 (0.0)	1 (0.1)	
Caribbean (Black or Black British)	44 (0.4)	1 (0.1)		2 (0.1)	1 (0.1)	
African (Black or Black British)	15 (0.1)	1 (0.1)		1 (0.0)	1 (0.1)	
Any other Black background	12 (0.1)	0 (0.0)		0 (0.0)	0 (0.0)	
Chinese (other ethnic group)	0 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
Any other ethnic group	24 (0.2)	2 (0.3)		3 (0.1)	2 (0.3)	
IMD decile (mean (sd))	5.75 (2.70)	5.88 (2.71)	0.049	5.98 (2.68)	5.88 (2.71)	0.037
Fixation (%)			0.244			0.033
Cementless	932 (8.9)	26 (3.8)		70 (3.4)	26 (3.8)	
Cemented	9411 (90.1)	640 (93.6)		1936 (94.3)	640 (93.6)	
Hybrid	98 (0.9)	18 (2.6)		46 (2.2)	18 (2.6)	

Cases per consultant per year (mean (sd))	91.12 (60.34)	89.63 (64.68)	0.024	89.96 (58.38)	89.63 (64.68)	0.005

Table A2.3 Patient characteristics before and after matching high usage UKRs (10+%) with TKRs for transition probabilities and hospital costs

	Before matching			After matching		
	TKR	UKR (usage 10+%)	SMD	TKR	UKR (usage 10+%)	SMD
Number of patients	75753	20686		60544	20682	
Age at surgery (mean (sd))	64.72 (9.30)	65.17 (9.41)	0.048	64.99 (9.27)	65.17 (9.41)	0.019
Unit type (%)			0.051			0.014
Public hospital	63990 (84.5)	17476 (84.5)		51198 (84.6)	17472 (84.5)	
Independent hospital	9098 (12.0)	2302 (11.1)		6852 (11.3)	2302 (11.1)	
Independent sector treatment centre	2665 (3.5)	908 (4.4)		2494 (4.1)	908 (4.4)	
Thromboprophylaxis						
Drugs (%)			0.118			0.039
Aspirin	9498 (12.5)	3364 (16.3)		9038 (14.9)	3362 (16.3)	
Direct thrombin inhibitor	2622 (3.5)	880 (4.3)		2444 (4.0)	879 (4.3)	
Unfractionated or low molecular weight heparin	397 (0.5)	92 (0.4)		281 (0.5)	92 (0.4)	
None/Unspecified	9325 (12.3)	2339 (11.3)		6989 (11.5)	2339 (11.3)	
Other	53187 (70.2)	13829 (66.9)		41248 (68.1)	13828 (66.9)	
Warfarin	724 (1.0)	182 (0.9)		544 (0.9)	182 (0.9)	
Mechanical (%)			0.099			0.029
None/Unspecified	9034 (11.9)	2486 (12.0)		7301 (12.1)	2486 (12.0)	
Foot pumps	7474 (9.9)	1659 (8.0)		5205 (8.6)	1659 (8.0)	
Intermittent calf compression	9166 (12.1)	3007 (14.5)		8319 (13.7)	3006 (14.5)	
Thromboembolic deterrent stockings	49069 (64.8)	13343 (64.5)		39144 (64.7)	13340 (64.5)	
Other	1010 (1.3)	191 (0.9)		575 (0.9)	191 (0.9)	
Gender (%)			0.017			0.005
M	39440 (52.1)	10656 (51.5)		31335 (51.8)	10655 (51.5)	
American Society of Anesthesiologists score (%)			0.033			0.027
1	16018 (21.1)	4299 (20.8)		12397 (20.5)	4299 (20.8)	
2	53087 (70.1)	14372 (69.5)		42685 (70.5)	14368 (69.5)	
3+	6648 (8.8)	2015 (9.7)		5462 (9.0)	2015 (9.7)	

Comorbidities (Charlson index) (%)			0.007			0.005
None	60768 (80.2)	16551 (80.0)		48502 (80.1)	16548 (80.0)	
Mild	12511 (16.5)	3459 (16.7)		10047 (16.6)	3459 (16.7)	
Moderate	1967 (2.6)	531 (2.6)		1584 (2.6)	530 (2.6)	
Severe	507 (0.7)	145 (0.7)		411 (0.7)	145 (0.7)	
Hypertension (mean (sd))	0.35 (0.48)	0.36 (0.48)	0.018	0.36 (0.48)	0.36 (0.48)	0.004
Ethnicity (%)			0.07			0.035
Undefined	9958 (13.1)	2944 (14.2)		8311 (13.7)	2944 (14.2)	
British (White)	61524 (81.2)	16506 (79.8)		48783 (80.6)	16505 (79.8)	
Irish (White)	411 (0.5)	123 (0.6)		355 (0.6)	123 (0.6)	
Any other White background	1401 (1.8)	440 (2.1)		1207 (2.0)	440 (2.1)	
White and Black Caribbean (Mixed)	29 (0.0)	13 (0.1)		29 (0.0)	13 (0.1)	
White and Black African (Mixed)	11 (0.0)	2 (0.0)		7 (0.0)	2 (0.0)	
White and Asian (Mixed)	42 (0.1)	16 (0.1)		42 (0.1)	16 (0.1)	
Any other Mixed background	31 (0.0)	11 (0.1)		30 (0.0)	11 (0.1)	
Indian (Asian or Asian British)	1068 (1.4)	265 (1.3)		802 (1.3)	265 (1.3)	
Pakistani (Asian or Asian British)	351 (0.5)	97 (0.5)		281 (0.5)	97 (0.5)	
Bangladeshi (Asian or Asian British)	26 (0.0)	6 (0.0)		23 (0.0)	6 (0.0)	
Any other Asian background	195 (0.3)	69 (0.3)		184 (0.3)	69 (0.3)	
Caribbean (Black or Black British)	259 (0.3)	52 (0.3)		175 (0.3)	52 (0.3)	
African (Black or Black British)	146 (0.2)	19 (0.1)		58 (0.1)	19 (0.1)	
Any other Black background	64 (0.1)	13 (0.1)		45 (0.1)	13 (0.1)	
Chinese (other ethnic group)	25 (0.0)	2 (0.0)		8 (0.0)	2 (0.0)	
Any other ethnic group	212 (0.3)	108 (0.5)		204 (0.3)	105 (0.5)	
IMD decile (mean (sd))	6.25 (2.67)	6.26 (2.68)	0.004	6.26 (2.67)	6.26 (2.68)	0.001
Fixation (%)			0.044			0.018
Cementless	5677 (7.5)	1704 (8.2)		4767 (7.9)	1704 (8.2)	
Cemented	68544 (90.5)	18461 (89.2)		54367 (89.8)	18459 (89.3)	
Hybrid	1532 (2.0)	521 (2.5)		1410 (2.3)	519 (2.5)	
Cases per consultant per year (mean (sd))	84.74 (58.78)	85.36 (55.18)	0.011	84.84 (58.89)	85.37 (55.18)	0.009

Table A2.4 Patient characteristics before and after matching high usage UKRs (10+%) with TKRs for quality of life

	Before matching			After matching		
	TKR	UKR (usage 10+%)	SMD	TKR	UKR (usage 10+%)	SMD
Number of patients	10441	2793		8379	2793	
Age at surgery (mean (sd))	64.38 (8.60)	65.01 (8.79)	0.073	64.96 (8.65)	65.01 (8.79)	0.005
Unit type (%)			0.079			0.024
Public hospital	7726 (74.0)	2072 (74.2)		6243 (74.5)	2072 (74.2)	
Independent hospital	2267 (21.7)	558 (20.0)		1692 (20.2)	558 (20.0)	
Independent sector treatment centre	448 (4.3)	163 (5.8)		444 (5.3)	163 (5.8)	
Thromboprophylaxis						
Drugs (%)			0.027			0.012
Aspirin	2065 (19.8)	538 (19.3)		1619 (19.3)	538 (19.3)	
Unfractionated or low molecular weight heparin	203 (1.9)	54 (1.9)		151 (1.8)	54 (1.9)	
None/Unspecified	2171 (20.8)	560 (20.1)		1694 (20.2)	560 (20.1)	
Other	5908 (56.6)	1614 (57.8)		4829 (57.6)	1614 (57.8)	
Warfarin	94 (0.9)	27 (1.0)		86 (1.0)	27 (1.0)	
Mechanical (%)			0.042			0.007
None/Unspecified	2428 (23.3)	635 (22.7)		1902 (22.7)	635 (22.7)	
Foot Pumps	887 (8.5)	226 (8.1)		677 (8.1)	226 (8.1)	
Intermittent calf compression	845 (8.1)	203 (7.3)		611 (7.3)	203 (7.3)	
Thromboembolic deterrent stockings	6154 (58.9)	1697 (60.8)		5087 (60.7)	1697 (60.8)	
Other	127 (1.2)	32 (1.1)		102 (1.2)	32 (1.1)	
Gender (%)			0.012			0.003
M	5511 (52.8)	1491 (53.4)		4462 (53.3)	1491 (53.4)	
American Society of Anesthesiologists score (%)			0.055			0.053
1	2183 (20.9)	605 (21.7)		1725 (20.6)	605 (21.7)	
2	7585 (72.6)	1973 (70.6)		6099 (72.8)	1973 (70.6)	
3+	673 (6.4)	215 (7.7)		555 (6.6)	215 (7.7)	
Comorbidities (Charlson index) (%)			0.063			0.017

None	8622 (82.6)	2296 (82.2)		6904 (82.4)	2296 (82.2)	
Mild	1496 (14.3)	398 (14.2)		1199 (14.3)	398 (14.2)	
Moderate	240 (2.3)	86 (3.1)		235 (2.8)	86 (3.1)	
Severe	83 (0.8)	13 (0.5)		41 (0.5)	13 (0.5)	
Hypertension (mean (sd))	0.35 (0.48)	0.36 (0.48)	0.025	0.35 (0.48)	0.36 (0.48)	0.008
Ethnicity (%)			0.064			0.016
Undefined	2253 (21.6)	606 (21.7)		1824 (21.8)	606 (21.7)	
British (White)	7643 (73.2)	2046 (73.3)		6129 (73.1)	2046 (73.3)	
Irish (White)	52 (0.5)	11 (0.4)		39 (0.5)	11 (0.4)	
Any other White background	225 (2.2)	66 (2.4)		201 (2.4)	66 (2.4)	
White and Black Caribbean (Mixed)	7 (0.1)	1 (0.0)		4 (0.0)	1 (0.0)	
White and Black African (Mixed)	0 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
White and Asian (Mixed)	1 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
Any other Mixed background	1 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
Indian (Asian or Asian British)	114 (1.1)	31 (1.1)		88 (1.1)	31 (1.1)	
Pakistani (Asian or Asian British)	34 (0.3)	10 (0.4)		28 (0.3)	10 (0.4)	
Bangladeshi (Asian or Asian British)	6 (0.1)	0 (0.0)		0 (0.0)	0 (0.0)	
Any other Asian background	10 (0.1)	2 (0.1)		5 (0.1)	2 (0.1)	
Caribbean (Black or Black British)	44 (0.4)	7 (0.3)		21 (0.3)	7 (0.3)	
African (Black or Black British)	15 (0.1)	4 (0.1)		12 (0.1)	4 (0.1)	
Any other Black background	12 (0.1)	1 (0.0)		4 (0.0)	1 (0.0)	
Chinese (other ethnic group)	0 (0.0)	0 (0.0)		0 (0.0)	0 (0.0)	
Any other ethnic group	24 (0.2)	8 (0.3)		24 (0.3)	8 (0.3)	
IMD decile (mean (sd))	5.75 (2.70)	5.73 (2.75)	0.009	5.74 (2.72)	5.73 (2.75)	0.006
Fixation (%)			0.137			0.085
Cementless	932 (8.9)	322 (11.5)		912 (10.9)	322 (11.5)	
Cemented	9411 (90.1)	2409 (86.3)		7369 (87.9)	2409 (86.3)	
Hybrid	98 (0.9)	62 (2.2)		98 (1.2)	62 (2.2)	
Cases per consultant per year (mean (sd))	91.12 (60.34)	91.04 (54.59)	0.001	90.85 (60.48)	91.04 (54.59)	0.003

PARAMETRIC MODELS FOR REVISION AND MORTALITY

Figure A3.2 Parametric models for revision for male, <60 subgroups

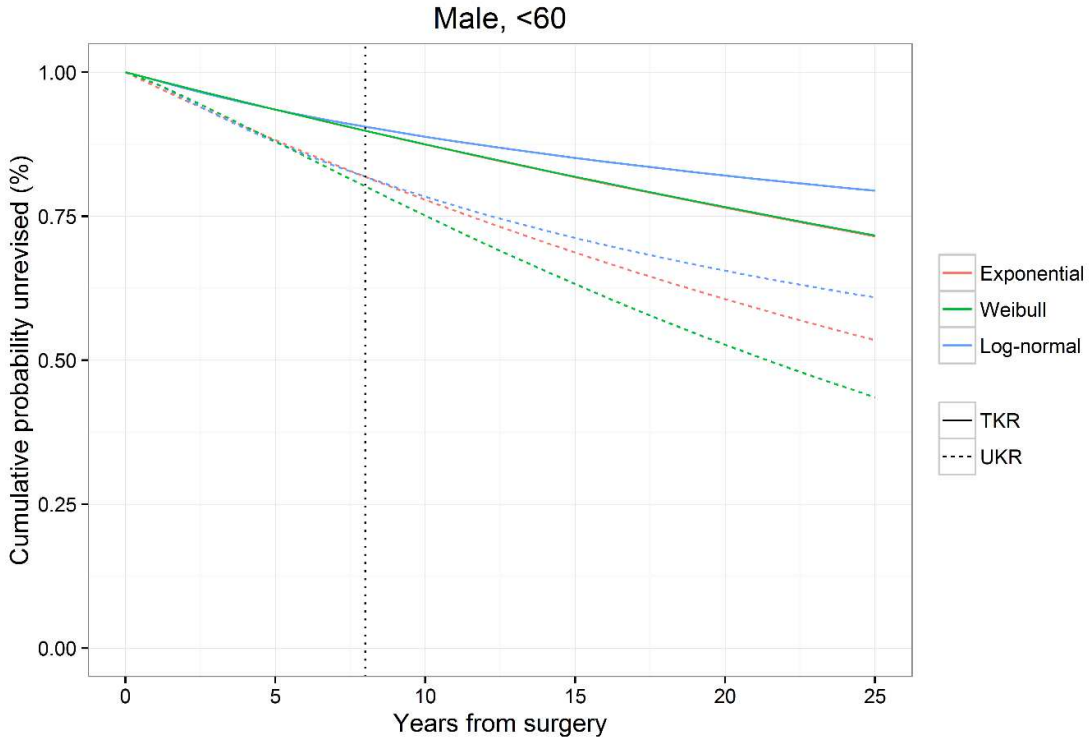

Table A3.3 AIC of parametric models for revision for male, <60 subgroups

Procedure	Distribution	AIC
TKR	Exponential	5,143
TKR	Weibull	5,145
TKR	Log-normal	5,123
UKR	Exponential	2,964
UKR	Weibull	2,957
UKR	Log-normal	2,949

Figure A3.2 Parametric models for revision for female, <60 subgroups

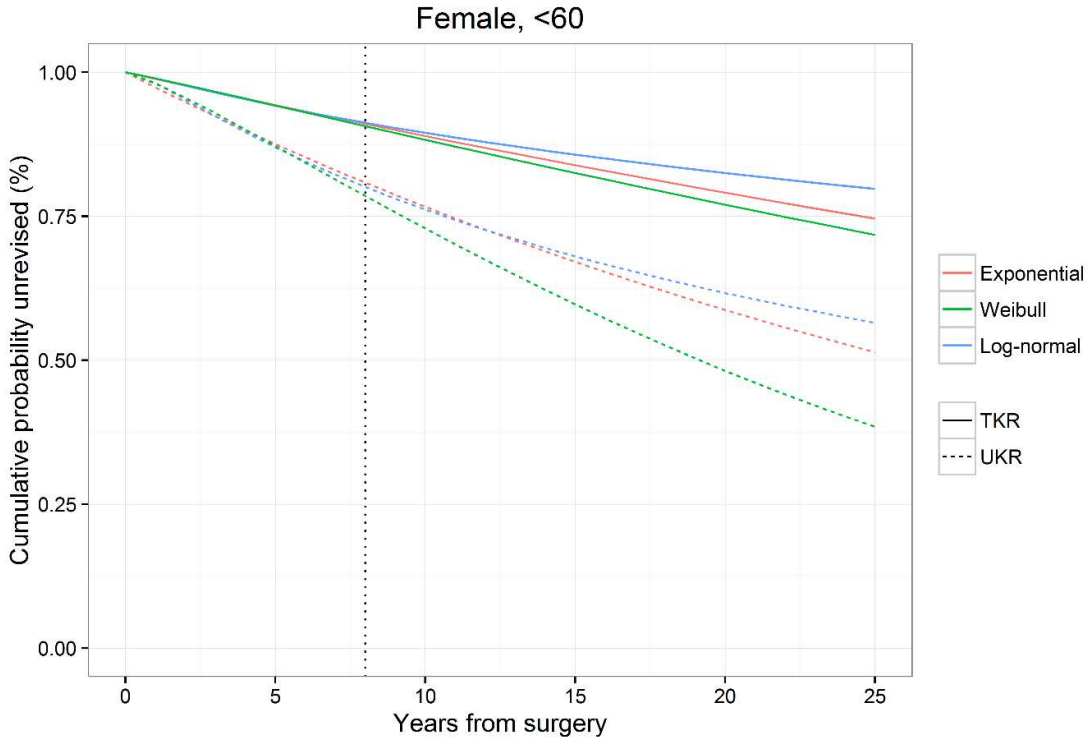

Table A3.2 AIC of parametric models for revision for female, <60 subgroups

Procedure	Distribution	AIC
TKR	Exponential	4,826
TKR	Weibull	4,826
TKR	Log-normal	4,799
UKR	Exponential	3,564
UKR	Weibull	3,548
UKR	Log-normal	3,525

Figure A3.3 Parametric models for revision for male, 60 to 75 subgroups

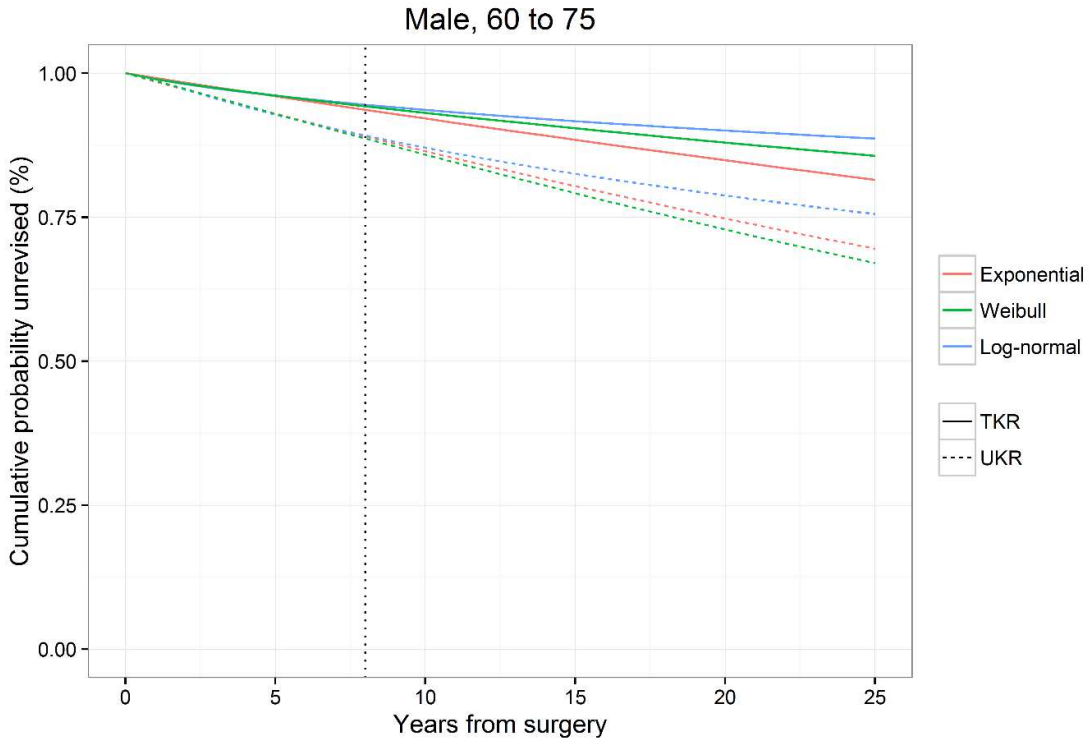

Table A3.3 AIC of parametric models for revision for male, 60 to 75 subgroups

Procedure	Distribution	AIC
TKR	Exponential	7,258
TKR	Weibull	7,237
TKR	Log-normal	7,197
UKR	Exponential	3,863
UKR	Weibull	3,863
UKR	Log-normal	3,833

Figure A3.4 Parametric models for revision for female, 60 to 75 subgroups

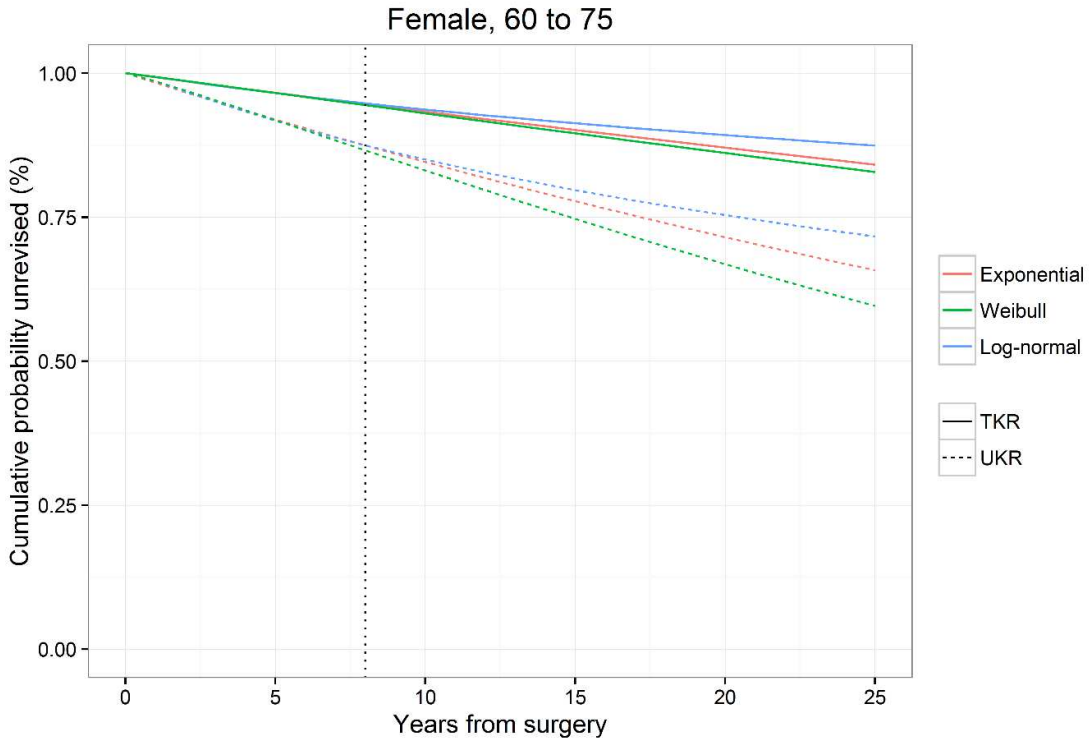

Table A3.4 AIC of parametric models for revision for female, 60 to 75 subgroups

Procedure	Distribution	AIC
TKR	Exponential	5,379
TKR	Weibull	5,380
TKR	Log-normal	5,359
UKR	Exponential	3,626
UKR	Weibull	3,622
UKR	Log-normal	3,608

Figure A3.5 Parametric models for revision for male, 75+ subgroups

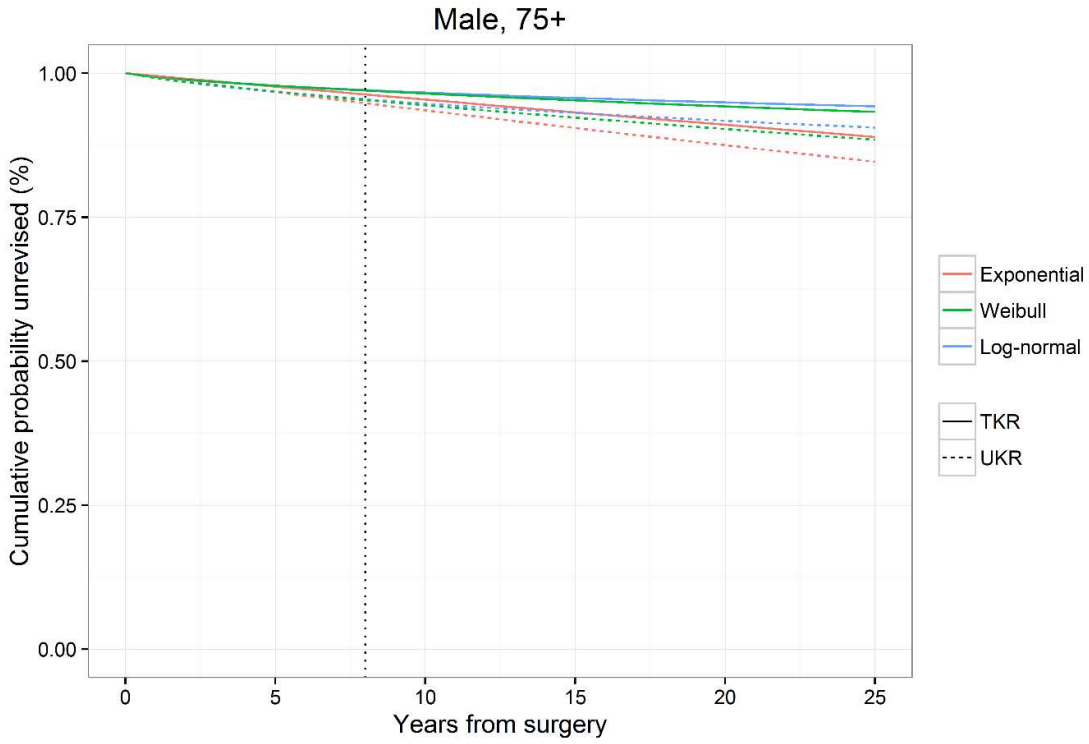

Table A3.5 AIC of parametric models for revision for male, 75+ subgroups

Procedure	Distribution	AIC
TKR	Exponential	1,020
TKR	Weibull	1,011
TKR	Log-normal	1,004
UKR	Exponential	507
UKR	Weibull	507
UKR	Log-normal	503

Figure A3.6 Parametric models for revision for female, 75+ subgroups

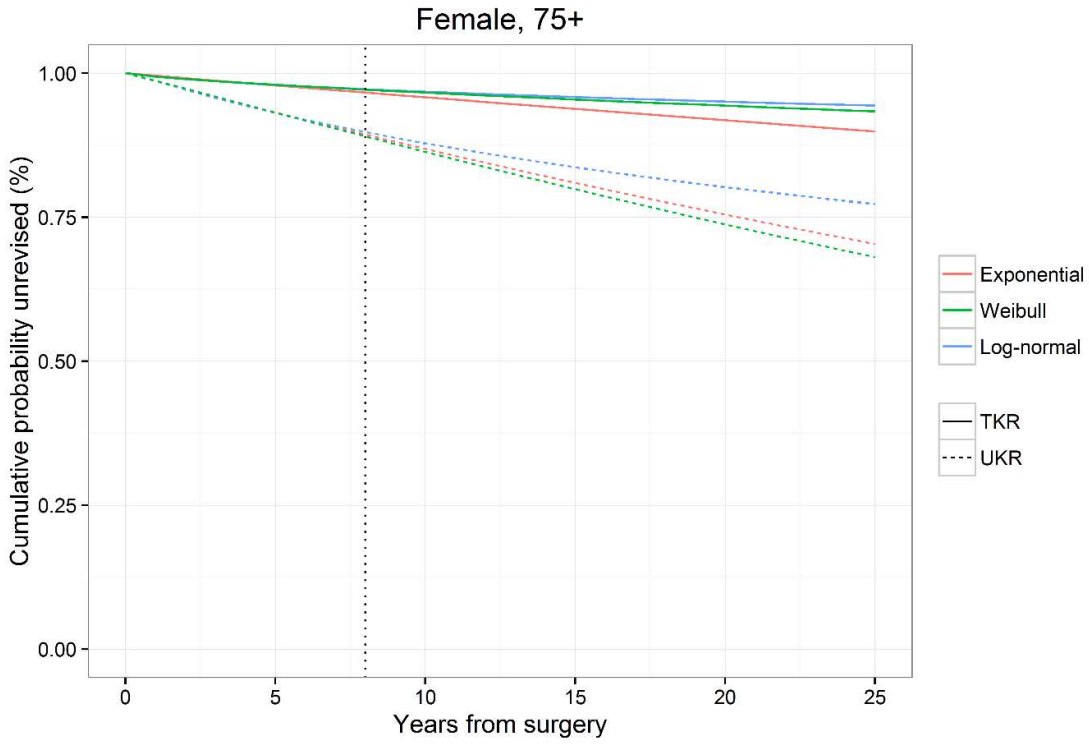

Table A3.6 AIC of parametric models for revision for female, 75+ subgroups

Procedure	Distribution	AIC
TKR	Exponential	997
TKR	Weibull	991
TKR	Log-normal	985
UKR	Exponential	949
UKR	Weibull	951
UKR	Log-normal	949

Figure A3.7 Parametric models for revision for usage, <10 subgroups

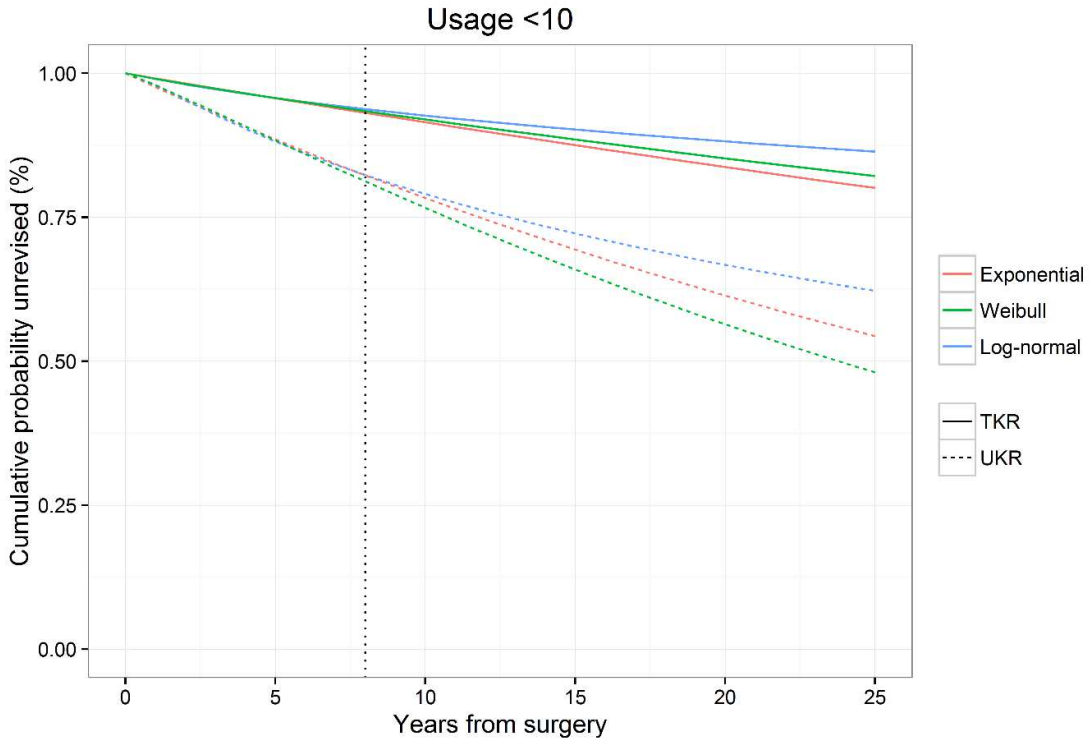

Table A3.7 AIC of parametric models for revision for usage, <10 subgroups

Procedure	Distribution	AIC
TKR	Exponential	4,615
TKR	Weibull	4,614
TKR	Log-normal	4,591
UKR	Exponential	3,566
UKR	Weibull	3,563
UKR	Log-normal	3,534

Figure A3.8 Parametric models for revision for usage, 10+ subgroups

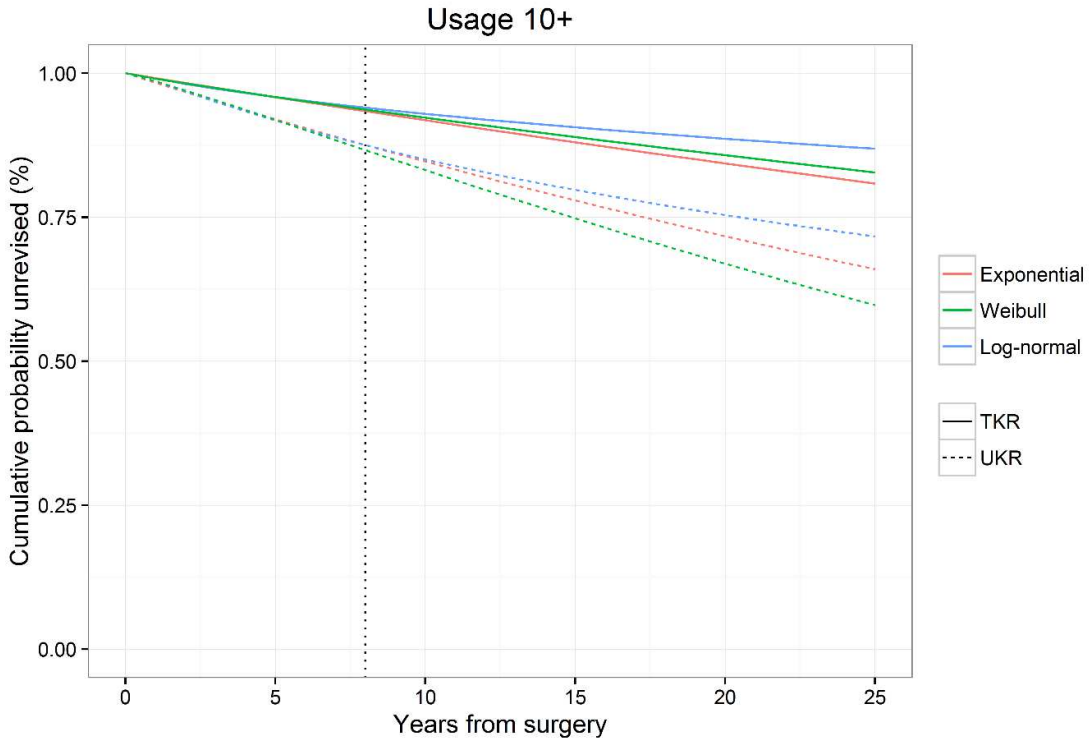

Table A3.8 AIC of parametric models for revision for usage, 10+ subgroups

Procedure	Distribution	AIC
TKR	Exponential	19,665
TKR	Weibull	19,657
TKR	Log-normal	19,563
UKR	Exponential	12,028
UKR	Weibull	12,010
UKR	Log-normal	11,956

Figure A3.9 Parametric models for mortality for male, <60 subgroups

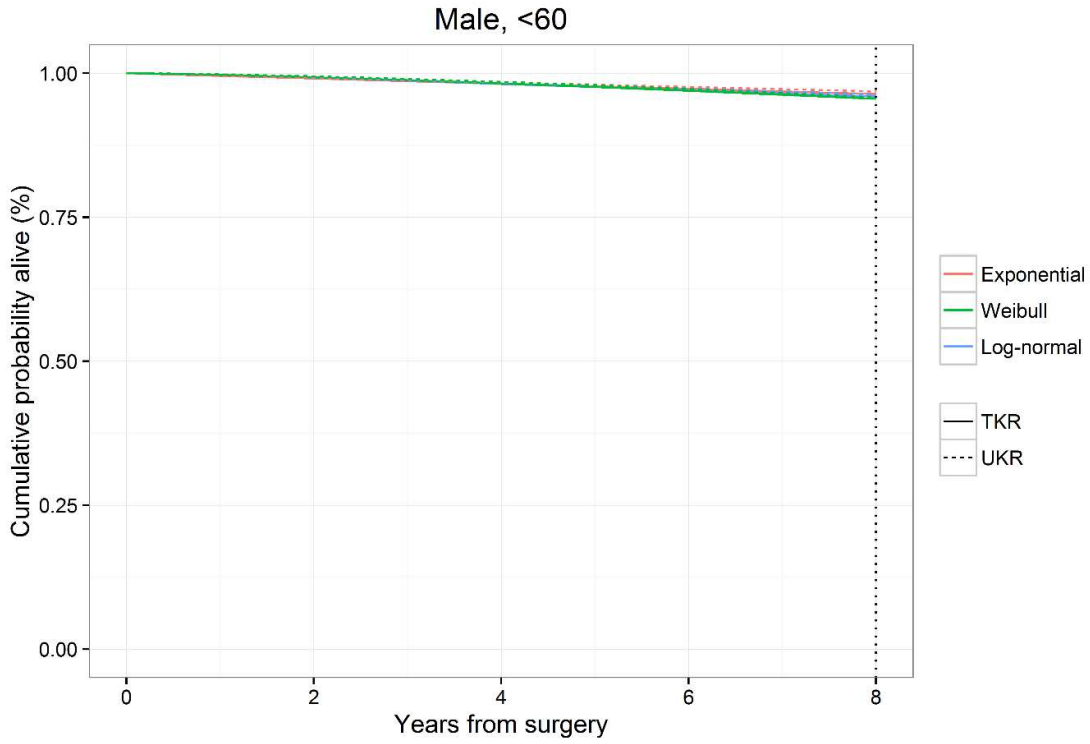

Table A3.9 AIC of parametric models for mortality for male, <60 subgroups

Procedure	Distribution	AIC
TKR	Exponential	2110
TKR	Weibull	2093
TKR	Log-normal	2096
UKR	Exponential	666
UKR	Weibull	657
UKR	Log-normal	662

Figure A3.10 Parametric models for mortality for female, <60 subgroups

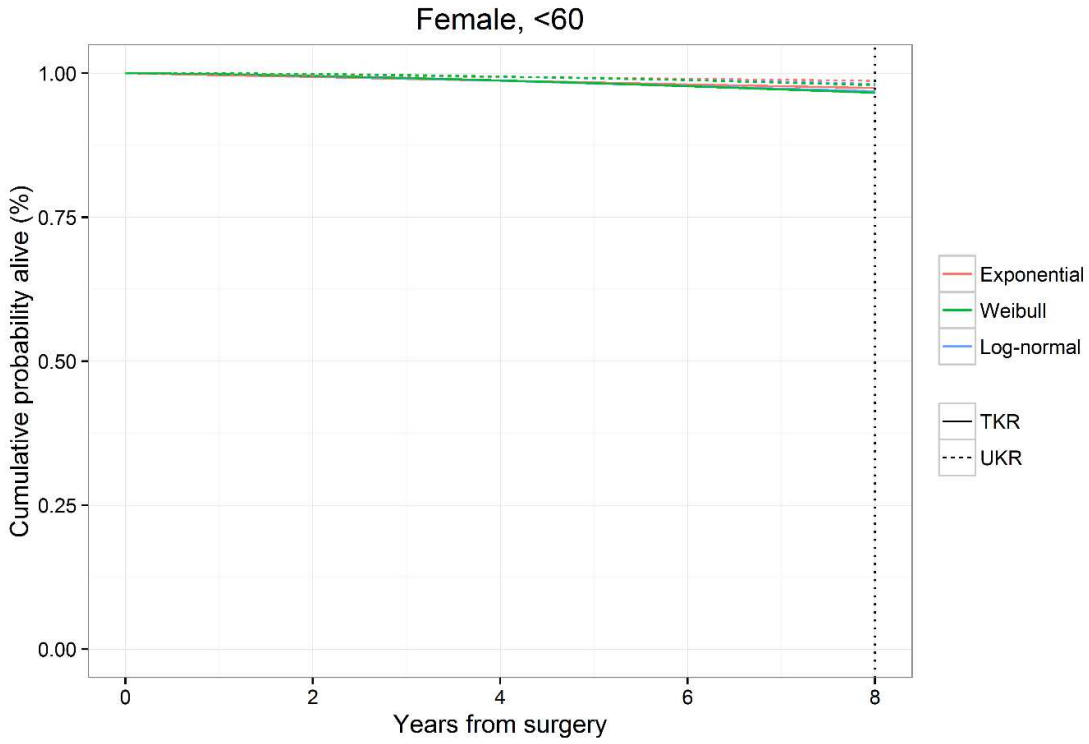

Table A3.10 AIC of parametric models for mortality for female, <60 subgroups

Procedure	Distribution	AIC
TKR	Exponential	1657
TKR	Weibull	1637
TKR	Log-normal	1635
UKR	Exponential	357
UKR	Weibull	348
UKR	Log-normal	349

Figure A3.11 Parametric models for mortality for male, 60 to 75 subgroups

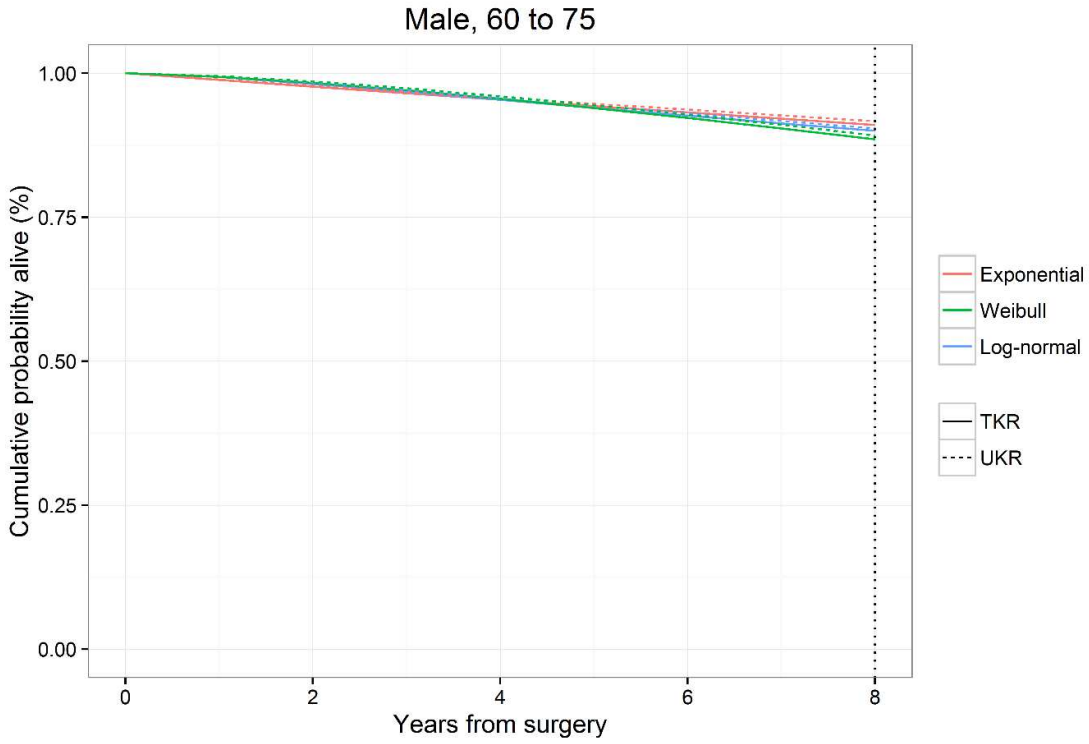

Table A3.11 AIC of parametric models for mortality for male, 60 to 75 subgroups

Procedure	Distribution	AIC
TKR	Exponential	9758
TKR	Weibull	9617
TKR	Log-normal	9676
UKR	Exponential	3050
UKR	Weibull	2996
UKR	Log-normal	3010

Figure A3.12 Parametric models for mortality for female, 60 to 75 subgroups

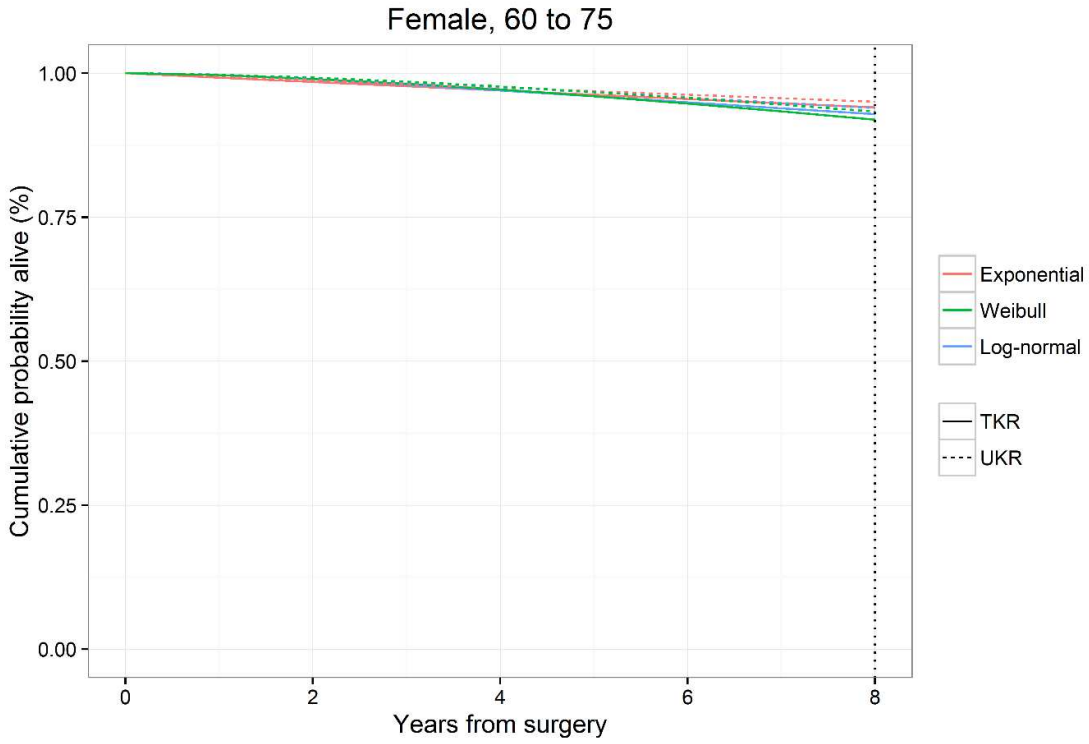

Table A3.12 AIC of parametric models for mortality for female, 60 to 75 subgroups

Procedure	Distribution	AIC
TKR	Exponential	5852
TKR	Weibull	5736
TKR	Log-normal	5764
UKR	Exponential	1638
UKR	Weibull	1606
UKR	Log-normal	1610

Figure A3.13 Parametric models for mortality for male, 75+ subgroups

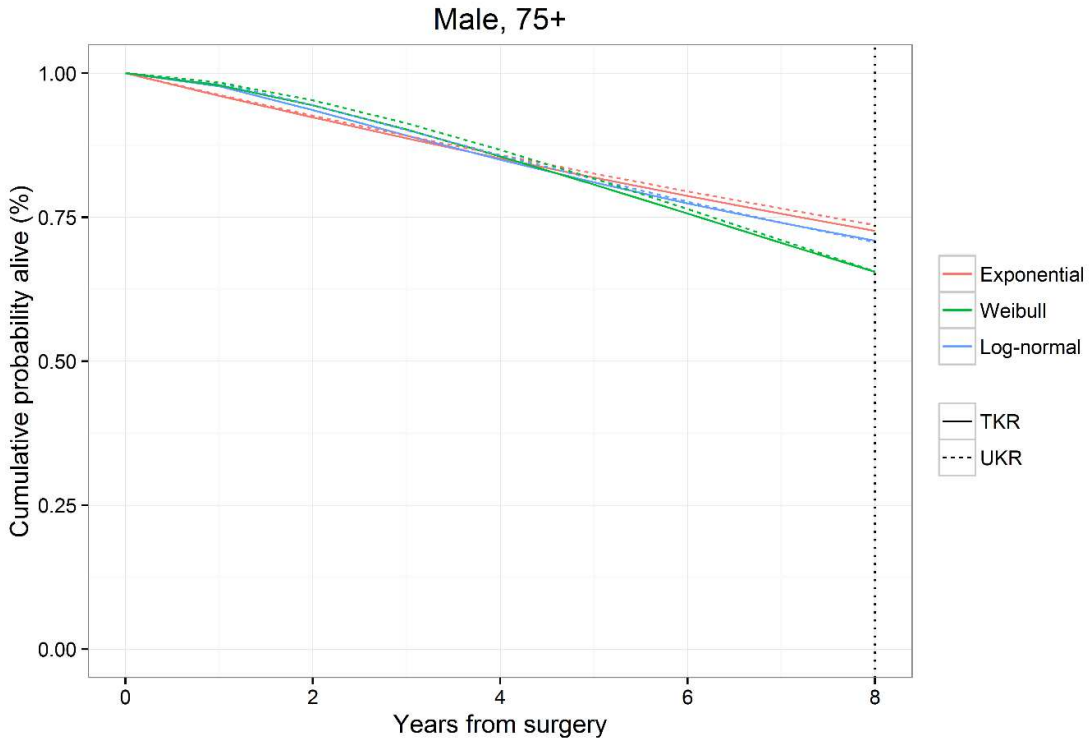

Table A3.13 AIC of parametric models for mortality for male, 75+ subgroups

Procedure	Distribution	AIC
TKR	Exponential	5758
TKR	Weibull	5645
TKR	Log-normal	5712
UKR	Exponential	2057
UKR	Weibull	1998
UKR	Log-normal	2026

Figure A3.14 Parametric models for mortality for female, 75+ subgroups

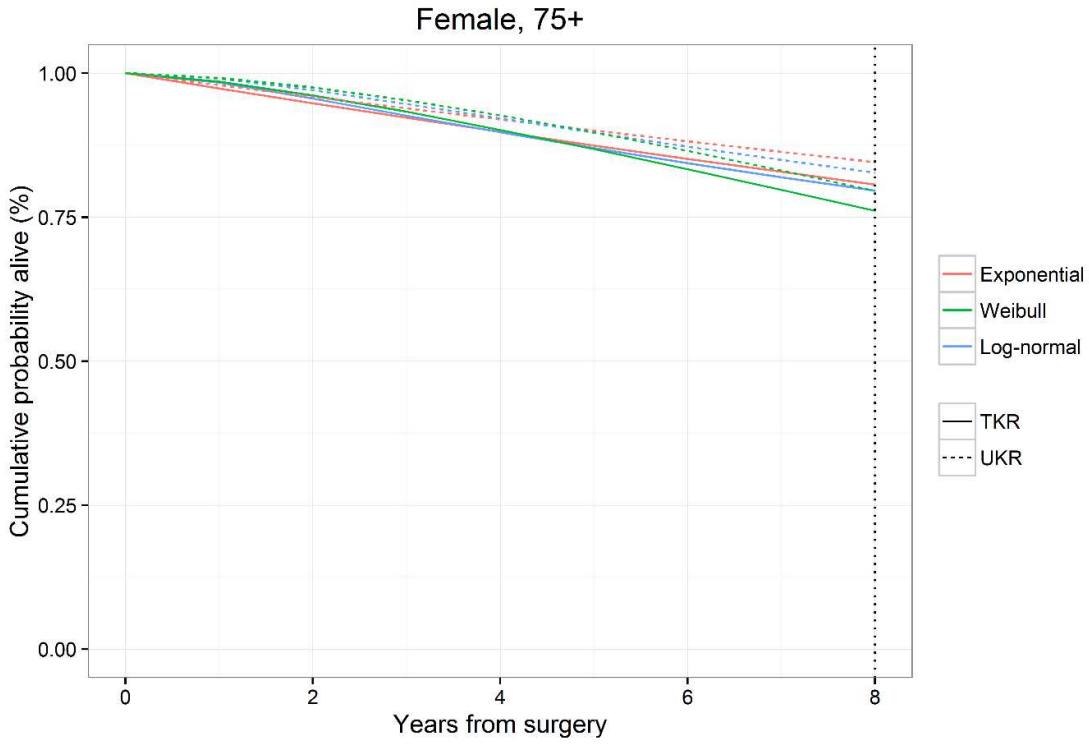

Table A3.14 AIC of parametric models for mortality for female, 75+ subgroups

Procedure	Distribution	AIC
TKR	Exponential	4482
TKR	Weibull	4415
TKR	Log-normal	4462
UKR	Exponential	1306
UKR	Weibull	1272
UKR	Log-normal	1293

Figure A3.15 Parametric models for mortality for usage, <10 subgroups

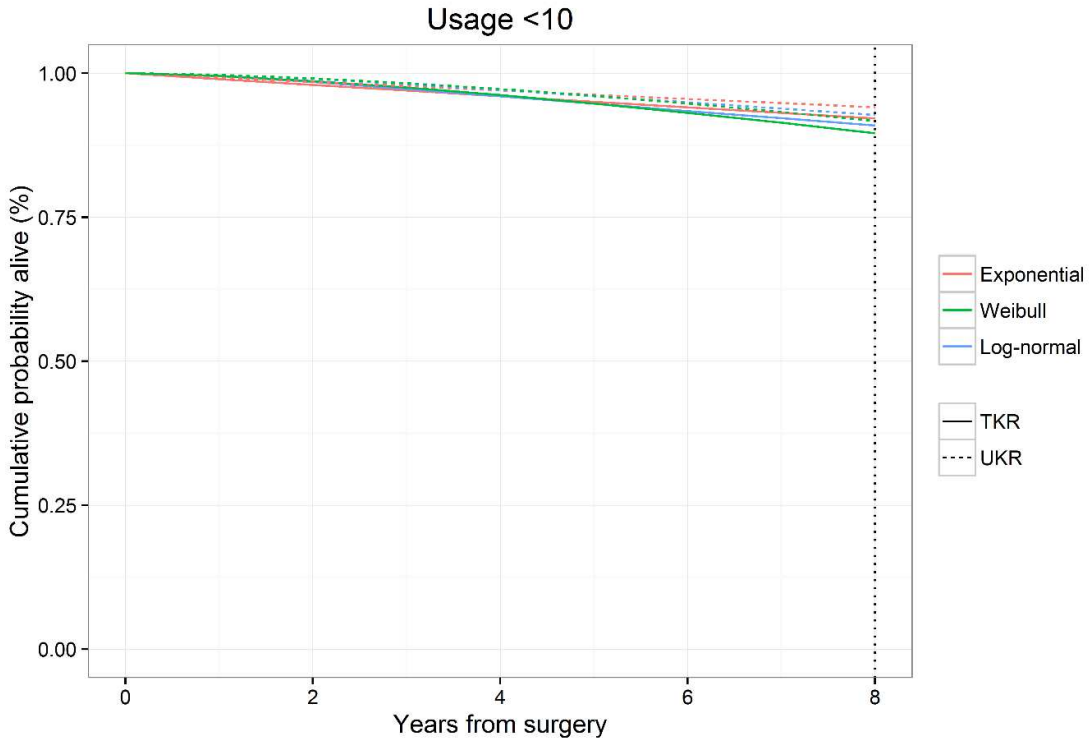

Table A3.15 AIC of parametric models for mortality for usage, <10 subgroups

Procedure	Distribution	AIC
TKR	Exponential	5164
TKR	Weibull	5069
TKR	Log-normal	5103
UKR	Exponential	1389
UKR	Weibull	1355
UKR	Log-normal	1366

Figure A3.16 Parametric models for mortality for usage, 10+ subgroups

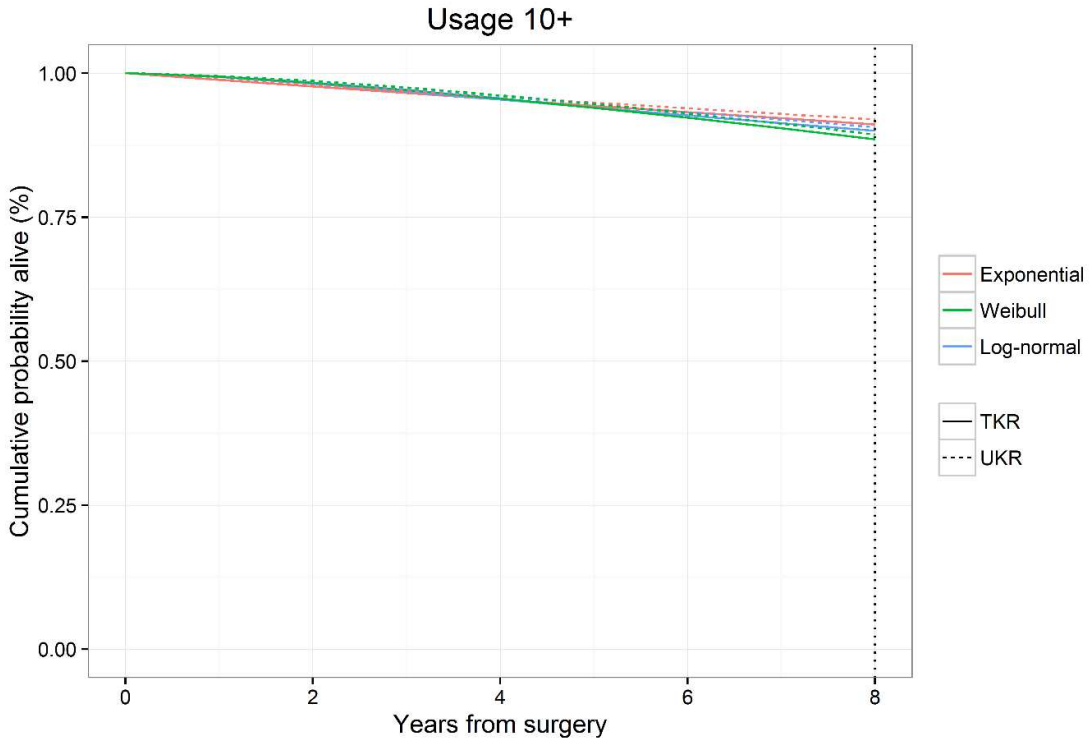

Table A3.16 AIC of parametric models for mortality for usage, 10+ subgroups

Procedure	Distribution	AIC
TKR	Exponential	25418
TKR	Weibull	25025
TKR	Log-normal	25187
UKR	Exponential	8262
UKR	Weibull	8094
UKR	Log-normal	8146

COSTS

Table A4.1 Hospital costs

	Procedure	Subgroup	N	Mean	SD	SE
Primary						
	TKR	<60, Female	10287	5968	1070	33
	UKR	<60, Female	3270	3910	2259	48
	TKR	<60, Male	10856	5965	1107	33
	UKR	<60, Male	3857	3935	2274	48
	TKR	60 to 70, Female	21480	6013	992	31
	UKR	60 to 70, Female	6567	3996	2257	48
	TKR	60 to 70, Male	18249	6047	988	31
	UKR	60 to 70, Male	5493	3996	2226	47
	TKR	>75, Female	5033	6186	1266	36
	UKR	>75, Female	1702	4035	2276	48
	TKR	>75, Male	5098	6131	1126	34
	UKR	>75, Male	1619	3993	2249	47
	TKR	<10	53832	6041	991	31
	UKR	<10	4210	4070	2224	47
	TKR	10+	15542	6002	1223	35
	UKR	10+	18213	3947	2260	48
Reoperation						
	TKR	<60, Female	497	2384	1979	44
	UKR	<60, Female	171	1822	1558	39
	TKR	<60, Male	549	2122	1776	42
	UKR	<60, Male	206	1680	1183	34
	TKR	60 to 70, Female	689	2361	2124	46
	UKR	60 to 70, Female	203	2220	2036	45
	TKR	60 to 70, Male	590	2258	2188	47
	UKR	60 to 70, Male	148	1929	1817	43

	TKR	>75, Female	114	2962	3158	56
	UKR	>75, Female	27	2496	2772	53
	TKR	>75, Male	107	2174	2045	45
	UKR	>75, Male	40	1973	2353	49
	TKR	<10	819	2323	2138	46
	UKR	<10	73	1577	1367	37
	TKR	10+	240	2291	2008	45
	UKR	10+	276	2104	1957	44
Revision						
	TKR	<60, Female	470	8154	2775	53
	UKR	<60, Female	300	6385	2507	50
	TKR	<60, Male	428	7937	2534	50
	UKR	<60, Male	367	6210	2379	49
	TKR	60 to 70, Female	598	7866	3748	61
	UKR	60 to 70, Female	347	6607	2365	49
	TKR	60 to 70, Male	428	8045	2684	52
	UKR	60 to 70, Male	326	6492	2364	49
	TKR	>75, Female	73	7820	3079	55
	UKR	>75, Female	39	6876	1824	43
	TKR	>75, Male	72	8049	2742	52
	UKR	>75, Male	85	6844	2145	46
	TKR	<10	643	7924	3541	60
	UKR	<10	189	6867	2410	49
	TKR	10+	216	8233	2443	49
	UKR	10+	541	6491	2352	48

Table A4.2 Primary care costs

Patient characteristics

	Before matching			After matching		
	TKR	UKR	SMD	TKR	UKR	SMD
Number of individuals	23,290	335		1,005	335	
Age at primary (mean (sd))	70.86 (8.79)	66.58 (9.74)	0.462	66.69 (9.26)	66.58 (9.74)	0.012
Gender: female (%)	13409 (57.6)	168 (50.1)	0.149	481 (47.9)	168 (50.1)	0.046
Year of primary (median [IQR])	2005 [2001, 2008]	2006 [2004, 2008]	0.469	2007 [2004, 2009]	2006 [2004, 2008]	0.004
Pain-related prescription costs in year prior to primary (median [IQR])	21 [2, 84]	16 [2, 59]	0.166	17 [2, 65]	16 [2, 59]	0.021
Consultation costs in year prior to primary (median [IQR])	322 [176, 552]	368 [184, 598]	0.142	368 [184, 644]	368 [184, 598]	0.007
Comorbidities at index date						
Chronic pulmonary disease (mean (sd))	0.20 (0.40)	0.15 (0.36)	0.132	0.16 (0.37)	0.15 (0.36)	0.025
Rheumatological disease (mean (sd))	0.07 (0.25)	0.05 (0.22)	0.068	0.05 (0.22)	0.05 (0.22)	0.005
Cerebrovascular disease (mean (sd))	0.05 (0.22)	0.03 (0.16)	0.135	0.03 (0.17)	0.03 (0.16)	0.012
Diabetes (mean (sd))	0.10 (0.30)	0.10 (0.29)	0.005	0.09 (0.29)	0.10 (0.29)	0.017
Myocardial infarction (mean (sd))	0.04 (0.21)	0.03 (0.18)	0.059	0.04 (0.19)	0.03 (0.18)	0.027
Congestive heart disease (mean (sd))	0.03 (0.17)	0.02 (0.13)	0.078	0.01 (0.12)	0.02 (0.13)	0.032
Renal disease (mean (sd))	0.07 (0.25)	0.07 (0.26)	0.029	0.07 (0.26)	0.07 (0.26)	<0.001
Cancer (mean (sd))	0.08 (0.27)	0.05 (0.21)	0.123	0.05 (0.22)	0.05 (0.21)	0.009
Metastatic tumour (mean (sd))	0.00 (0.05)	0.00 (0.05)	<0.001	0.00 (0.06)	0.00 (0.05)	0.017
Diabetes with complications (mean (sd))	0.02 (0.13)	0.02 (0.13)	0.016	0.02 (0.13)	0.02 (0.13)	<0.001
Peptic ulcer disease (mean (sd))	0.06 (0.23)	0.05 (0.22)	0.024	0.06 (0.24)	0.05 (0.22)	0.035
Peripheral vascular disease (mean (sd))	0.03 (0.17)	0.01 (0.12)	0.11	0.02 (0.14)	0.01 (0.12)	0.031
Dementia (mean (sd))	0.00 (0.05)	0.00 (0.00)	0.066	0.00 (0.00)	0.00 (0.00)	-
Mild liver disease (mean (sd))	0.00 (0.06)	0.01 (0.08)	0.042	0.01 (0.08)	0.01 (0.08)	<0.001
Hemiplegia (mean (sd))	0.00 (0.05)	0.00 (0.00)	0.066	0.00 (0.00)	0.00 (0.00)	-
Liver disease (mean (sd))	0.00 (0.02)	0.00 (0.00)	0.032	0.00 (0.00)	0.00 (0.00)	-

AIDS (mean (sd))	0.00 (0.01)	0.00 (0.00)	0.009	0.00 (0.00)	0.00 (0.00)	-

Costs

	N	Mean	SD	SE
<60, Male	82	328	301	33
60 to 70, Male	175	431	334	25
>75, Male	57	640	497	66
<60, Female	54	503	431	59
60 to 70, Female	164	478	406	32
>75, Female	62	554	418	53
All	594	471	396	16

QUALITY OF LIFE

Table A5.1 EQ-5D index scores

				Pre-op			Post-op		
	Procedure	Subgroup	N	Mean	SD	SE	Mean	SD	SE
Primary									
	TKR	<60, Male	1,487	0.44	0.30	0.008	0.70	0.28	0.007
	TKR	<60, Female	1,613	0.39	0.31	0.008	0.69	0.28	0.007
	TKR	60 to 70, Male	3,456	0.54	0.27	0.005	0.78	0.23	0.004
	TKR	60 to 70, Female	2,850	0.47	0.29	0.005	0.76	0.23	0.004
	TKR	>75, Male	641	0.56	0.25	0.010	0.79	0.21	0.008
	TKR	>75, Female	510	0.47	0.29	0.013	0.77	0.22	0.010
	UKR	<60, Male	473	0.44	0.30	0.014	0.71	0.29	0.013
	UKR	<60, Female	592	0.39	0.32	0.013	0.69	0.30	0.012
	UKR	60 to 70, Male	1,155	0.53	0.27	0.008	0.81	0.21	0.006
	UKR	60 to 70, Female	882	0.49	0.28	0.009	0.78	0.24	0.008
	UKR	>75, Male	241	0.54	0.25	0.016	0.84	0.18	0.012
	UKR	>75, Female	176	0.47	0.30	0.023	0.81	0.20	0.015
	TKR	<10	2,052	0.46	0.30	0.007	0.74	0.26	0.006
	UKR	<10	684	0.45	0.29	0.011	0.73	0.27	0.010
	TKR	10+	8,379	0.49	0.29	0.000	0.75	0.24	0.003
	UKR	10+	2,793	0.49	0.29	0.010	0.78	0.24	0.005
Revision									
	TKR		686	0.31	0.32	0.012	0.55	0.32	0.012
	UKR		248	0.38	0.31	0.020	0.61	0.27	0.017

SENSITIVITY ANALYSES.

Distribution of parametric model for revision risk: exponential

	TKR		UKR				
	QALYs	Costs	QALYs	Costs	Δ QALYs	Δ Costs	ICER (probability cost-effective*)
Male, <60	10.28 (10.06 to 10.47)	15,367 (14,690 to 16,020)	10.43 (10.13 to 10.72)	13,701 (12,986 to 14,370)	0.16 (-0.17 to 0.50)	-1,666 (-1,931 to -1,411)	UKR dominant (92%)
Male, 60-75	8.58 (8.49 to 8.68)	13,455 (12,710 to 14,286)	8.82 (8.66 to 8.97)	11,877 (11,114 to 12,696)	0.24 (0.05 to 0.41)	-1,578 (-1,796 to -1,382)	UKR dominant (100%)
Male, 75+	5.60 (5.48 to 5.71)	11,529 (10,591 to 12,639)	5.80 (5.64 to 5.95)	9,503 (8,515 to 10,620)	0.19 (0.01 to 0.37)	-2,026 (-2,214 to -1,833)	UKR dominant (100%)
Female, <60	10.70 (10.48 to 10.90)	16,794 (15,959 to 17,745)	10.81 (10.46 to 11.12)	15,743 (14,831 to 16,688)	0.11 (-0.28 to 0.45)	-1,050 (-1,384 to -747)	UKR dominant (78%)
Female, 60-75	8.97 (8.86 to 9.08)	13,764 (12,993 to 14,538)	9.27 (9.07 to 9.47)	12,664 (11,831 to 13,500)	0.30 (0.08 to 0.51)	-1,100 (-1,320 to -874)	UKR dominant (100%)
Female, 75+	6.01 (5.81 to 6.16)	11,483 (10,584 to 12,437)	6.46 (6.19 to 6.70)	10,264 (9,265 to 11,236)	0.45 (0.16 to 0.75)	-1,220 (-1,495 to -940)	UKR dominant (100%)

Expected (mean) values with 95% confidence intervals in parentheses. UKR is considered 'dominant' if it is expected to improve health outcomes and reduce health care costs. *Given a cost-effectiveness threshold of £20,000.

Distribution of parametric model for revision risk: Log-normal

	TKR			UKR				
	Proportion revised	QALYs	Costs	QALYs	Costs	Δ QALYs	Δ Costs	ICER (probability cost-effective*)
Male, <60	19.2% (16.9% to 21.8%)	10.35 (10.14 to 10.56)	14,812 (14,135 to 15,507)	10.49 (10.16 to 10.82)	13,071 (12,350 to 13,798)	0.14 (-0.22 to 0.47)	-1,742 (-2,018 to -1,447)	UKR dominant (89%)
Male, 60-75	8.6% (7.3% to 10.1%)	8.62 (8.53 to 8.71)	13,186 (12,471 to 13,977)	8.86 (8.69 to 9.00)	11,643 (10,936 to 12,441)	0.23 (0.04 to 0.40)	-1,544 (-1,779 to -1,292)	UKR dominant (100%)
Male, 75+	3.3% (1.6% to 6.4%)	5.61 (5.50 to 5.72)	11,438 (10,519 to 12,541)	5.81 (5.63 to 5.96)	9,421 (8,456 to 10,529)	0.19 (0.01 to 0.36)	-2,017 (-2,358 to -1,613)	UKR dominant (100%)
Female, <60	20.1% (17.5% to 22.6%)	10.75 (10.54 to 10.95)	16,367 (15,426 to 17,302)	10.84 (10.50 to 11.15)	15,081 (14,165 to 15,958)	0.08 (-0.29 to 0.45)	-1,286 (-1,615 to -958)	UKR dominant (77%)
Female, 60-75	9.9% (8.2% to 11.9%)	8.99 (8.88 to 9.10)	13,621 (12,870 to 14,439)	9.31 (9.10 to 9.50)	12,364 (11,581 to 13,152)	0.32 (0.08 to 0.54)	-1,257 (-1,524 to -1,013)	UKR dominant (100%)
Female, 75+	3.4% (1.8% to 6.5%)	6.02 (5.80 to 6.16)	11,389 (10,524 to 12,368)	6.47 (6.16 to 6.70)	10,108 (9,168 to 11,159)	0.45 (0.16 to 0.73)	-1,281 (-1,685 to -897)	UKR dominant (100%)

Expected (mean) values with 95% confidence intervals in parentheses. UKR is considered 'dominant' if it is expected to improve health outcomes and reduce health care costs. *Given a cost-effectiveness threshold of £20,000.

Health utility: re-revision equal to revision

	TKR		UKR				
	QALYs	Costs	QALYs	Costs	Δ QALYs	Δ Costs	ICER (probability cost-effective*)
Male, <60	10.32 (10.06 to 10.47)	15,357 (14,706 to 16,016)	10.49 (10.18 to 10.82)	14,134 (13,472 to 14,795)	0.16 (-0.11 to 0.57)	-1,223 (-1,417 to -988)	UKR dominant (95%)
Male, 60-75	8.62 (8.51 to 8.70)	13,307 (12,563 to 14,052)	8.83 (8.68 to 8.98)	11,952 (11,199 to 12,717)	0.21 (0.04 to 0.41)	-1,355 (-1,594 to -1,131)	UKR dominant (100%)
Male, 75+	5.61 (5.49 to 5.72)	11,454 (10,515 to 12,565)	5.81 (5.64 to 5.96)	9,450 (8,476 to 10,614)	0.19 (0.01 to 0.38)	-2,005 (-2,457 to -1,480)	UKR dominant (100%)
Female, <60	10.73 (10.46 to 10.86)	16,961 (16,099 to 17,907)	10.90 (10.57 to 11.22)	16,360 (15,480 to 17,287)	0.17 (-0.14 to 0.62)	-601 (-867 to -346)	UKR dominant (91%)
Female, 60-75	8.98 (8.85 to 9.07)	13,814 (13,019 to 14,606)	9.28 (9.09 to 9.47)	12,878 (12,108 to 13,711)	0.30 (0.09 to 0.54)	-935 (-1,192 to -685)	UKR dominant (100%)
Female, 75+	6.03 (5.81 to 6.17)	11,410 (10,487 to 12,500)	6.50 (6.24 to 6.72)	10,308 (9,377 to 11,399)	0.47 (0.21 to 0.75)	-1,102 (-1,622 to -667)	UKR dominant (100%)

Expected (mean) values with 95% confidence intervals in parentheses. UKR is considered 'dominant' if it is expected to improve health outcomes and reduce health care costs. *Given a cost-effectiveness threshold of £20,000.

Cost: cost of re-revision 50% higher than revision

	TKR		UKR				
	QALYs	Costs	QALYs	Costs	Δ QALYs	Δ Costs	ICER (probability cost-effective*)
Male, <60	10.28 (10.06 to 10.47)	13,638 (13,060 to 14,237)	10.39 (10.09 to 10.69)	12,415 (11,859 to 13,039)	0.12 (-0.23 to 0.45)	-1,223 (-1,432 to -1,028)	UKR dominant (83%)
Male, 60-75	8.61 (8.50 to 8.70)	13,307 (12,571 to 14,151)	8.81 (8.66 to 8.96)	11,952 (11,219 to 12,817)	0.20 (0.03 to 0.39)	-1,355 (-1,598 to -1,103)	UKR dominant (100%)
Male, 75+	5.61 (5.48 to 5.72)	11,454 (10,460 to 12,626)	5.80 (5.63 to 5.96)	9,450 (8,503 to 10,679)	0.19 (0.00 to 0.37)	-2,005 (-2,445 to -1,542)	UKR dominant (100%)
Female, <60	10.68 (10.48 to 10.88)	16,961 (15,994 to 17,808)	10.78 (10.44 to 11.06)	16,360 (15,406 to 17,199)	0.10 (-0.33 to 0.46)	-601 (-893 to -348)	UKR dominant (73%)
Female, 60-75	8.96 (8.85 to 9.08)	13,814 (13,026 to 14,588)	9.24 (9.05 to 9.44)	12,878 (12,050 to 13,727)	0.28 (0.04 to 0.51)	-935 (-1,168 to -705)	UKR dominant (100%)
Female, 75+	6.02 (5.82 to 6.16)	11,410 (10,541 to 12,425)	6.46 (6.17 to 6.68)	10,308 (9,362 to 11,339)	0.44 (0.15 to 0.73)	-1,102 (-1,623 to -683)	UKR dominant (100%)

Expected (mean) values with 95% confidence intervals in parentheses. UKR is considered 'dominant' if it is expected to improve health outcomes and reduce health care costs. *Given a cost-effectiveness threshold of £20,000.

Consolidated Health Economic Evaluation Reporting Standards (CHEERS) Checklist
Items to include when reporting economic evaluations of health interventions

Section/Topic	Item No	Recommendation	Reported on page No / Line No
Title and abstract			
Title	1	Identify the study as an economic evaluation or use more specific terms such as "cost-effectiveness analysis", and describe the interventions compared.	**Title page**
Abstract	2	Provide a structured summary of objectives, perspective, setting, methods (including study design and inputs), results (including base case and uncertainty analyses), and conclusions.	**Page 1, lines 1-29**
Introduction			
Background and objectives	3	Provide an explicit statement of the broader context for the study.	**Page 3, lines 46-68**
		Present the study question and its relevance for health policy or practice decisions.	**Page 3, lines 68-71**
Methods			
Target population and subgroups	4	Describe characteristics of the base case population and subgroups analysed, including why they were chosen.	**Page 3, lines 73-80**
Setting and location	5	State relevant aspects of the system(s) in which the decision(s) need(s) to be made.	**Page 3, lines 95-99**
Study perspective	6	Describe the perspective of the study and relate this to the costs being evaluated.	**Page 4, lines 92-99**
Comparators	7	Describe the interventions or strategies being compared and state why they were chosen.	**Page 3, lines 46-60**
Time horizon	8	State the time horizon(s) over which costs and consequences are being evaluated and say why appropriate.	**Page 3, lines 82-83**
Discount rate	9	Report the choice of discount rate(s) used for costs and outcomes and say why appropriate.	**Page 5, lines 137-145**
Choice of health outcomes	10	Describe what outcomes were used as the measure(s) of benefit in the evaluation and their relevance for the type of analysis performed.	**Page 5, lines 141-158**
Measurement of effectiveness	11a	*Single study-based estimates:* Describe fully the design features of the single effectiveness study and why the single study was a sufficient source of clinical effectiveness data.	**Page 4, lines 100-122**
	11b	*Synthesis-based estimates:* Describe fully the methods used for identification of included studies and synthesis of clinical	

		effectiveness data.	
Measurement and valuation of preference-based outcomes	12	If applicable, describe the population and methods used to elicit preferences for outcomes.	**Page 5, lines 140-158**
Estimating resources and costs	13a	*Single study-based economic evaluation:* Describe approaches used to estimate resource use associated with the alternative interventions. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs.	
	13b	*Model-based economic evaluation:* Describe approaches and data sources used to estimate resource use associated with model health states. Describe primary or secondary research methods for valuing each resource item in terms of its unit cost. Describe any adjustments made to approximate to opportunity costs.	**Pages 4-55, lines 123-136**
Currency, price data, and conversion	14	Report the dates of the estimated resource quantities and unit costs. Describe methods for adjusting estimated unit costs to the year of reported costs if necessary. Describe methods for converting costs into a common currency base and the exchange rate.	**Page 5, lines 138-139**
Choice of model	15	Describe and give reasons for the specific type of decision-analytical model used. Providing a figure to show model structure is strongly recommended.	**Pages 3-4, lines 81-91**
Assumptions	16	Describe all structural or other assumptions underpinning the decision-analytical model.	**Pages 4-5, lines 88-91**
Analytic methods	17	Describe all analytical methods supporting the evaluation. This could include methods for dealing with skewed, missing, or censored data; extrapolation methods; methods for pooling data; approaches to validate or make adjustments (such as half cycle corrections) to a model; and methods for handling population heterogeneity and uncertainty.	**Page 5, lines 159-167**
Results			
Study parameters	18	Report the values, ranges, references, and, if used, probability distributions for all parameters. Report reasons or sources for distributions used to represent uncertainty where appropriate. Providing a table to show the input values is strongly recommended.	**Appendix**
Incremental costs and outcomes	19	For each intervention, report mean values for the main categories of estimated costs and outcomes of interest, as well as mean differences between the comparator groups. If applicable, report incremental cost-effectiveness ratios.	**Tables 1 and 3**
Characterizing uncertainty	20a	*Single study-based economic evaluation:* Describe the effects of sampling uncertainty for the estimated incremental cost and incremental effectiveness parameters, together with the impact of methodological assumptions (such as discount rate, study perspective).	

	20b	*Model-based economic evaluation:* Describe the effects on the results of uncertainty for all input parameters, and uncertainty related to the structure of the model and assumptions.	**Tables 1, 2 and 3**
Characterizing heterogeneity	21	If applicable, report differences in costs, outcomes, or cost-effectiveness that can be explained by variations between subgroups of patients with different baseline characteristics or other observed variability in effects that are not reducible by more information.	**Tables 1, 2 and 3**
Discussion			
Study findings, limitations, generalizability, and current knowledge	22	Summarise key study findings and describe how they support the conclusions reached. Discuss limitations and the generalisability of the findings and how the findings fit with current knowledge.	**Pages 6-7, lines 192-253**
Other			
Source of funding	23	Describe how the study was funded and the role of the funder in the identification, design, conduct, and reporting of the analysis. Describe other non-monetary sources of support.	**Page 8, lines 265-267**
Conflicts of interest	24	Describe any potential for conflict of interest of study contributors in accordance with journal policy. In the absence of a journal policy, we recommend authors comply with International Committee of Medical Journal Editors recommendations.	**Page 8, lines 273-277**