Hunt, L. P., Blom, A. W., Matharu, G., Kunutsor, S. K., Beswick, A. D., Wilkinson, J. M., & Whitehouse, M. R. (2021). Patients Receiving A Primary Unicompartamental Knee Replacement Have A Higher Risk Of Revision But A Lower Risk Of Mortality Than Predicted Had They Received A Total Knee Replacement: Data From The National Joint Registry for England, Wales, Northern Ireland and the Isle of Man. *Journal of Arthroplasty*, 36(2), 471-477.e6.
<https://doi.org/10.1016/j.arth.2020.08.063>

Peer reviewed version

License (if available):
CC BY-NC-ND

Link to published version (if available):
[10.1016/j.arth.2020.08.063](https://doi.org/10.1016/j.arth.2020.08.063)

[Link to publication record in Explore Bristol Research](#)
PDF-document

This is the author accepted manuscript (AAM). The final published version (version of record) is available online via Elsevier at <https://www.sciencedirect.com/science/article/pii/S0883540320309724>. Please refer to any applicable terms of use of the publisher.

University of Bristol - Explore Bristol Research

General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available:
<http://www.bristol.ac.uk/red/research-policy/pure/user-guides/ebr-terms/>

The Journal of Arthroplasty

Patients Receiving A Primary Unicompartmental Knee Replacement Have A Higher Risk Of Revision But A Lower Risk Of Mortality Than Predicted Had They Received A Total Knee Replacement: Data From The National Joint Registry for England, Wales, Northern Ireland and the Isle of Man

--Manuscript Draft--

Manuscript Number:	JOA-D-20-00941R1
Article Type:	Original Article
Keywords:	outcomes; Mortality; revision rates; total knee replacement; unicompartmental knee
Corresponding Author:	Gulraj S Matharu, BSc (hons), MBChB, MRCS The Royal Orthopaedic Hospital Birmingham, UNITED KINGDOM
First Author:	Linda P Hunt
Order of Authors:	Linda P Hunt Ashley W Blom Gulraj S Matharu, BSc (hons), MBChB, MRCS Setor K Kunutsor Andrew Beswick J. Mark Wilkinson Michael R Whitehouse
Manuscript Region of Origin:	Europe
Abstract:	<p>Background: To determine unicompartmental (UKR) and total knee replacement (TKR) revision rates, compare UKR revision rates with what they would have been had they received TKR instead, subsequent re-revision and 90-day mortality rates.</p> <p>Methods: Using National Joint Registry data, we estimated UKR and TKR revision and mortality rates. Flexible Parametric Survival modelling (FPM) was used to model failure in TKR and make estimates for UKR. Kaplan-Meier estimates were used to compare cumulative re-revision for revised UKRs and TKRs.</p> <p>Results: 10-year UKR revision rates were 2.5-times higher than expected from TKR, equivalent to 70 excess revisions/1,000 cases within 10-years (5,861 excess revisions in this cohort). Revision rates were 2.5 times higher for the highest quartile volume UKR surgeons compared to the same quartile for TKR, and 3.9 times higher for the lowest quartiles respectively. Re-revision rates of revised TKRs (10-years=17.5%; 95%CI=16.4,18.7) were similar to revised UKRs (15.2%; 95%CI=13.4,17.1) and higher than revision rates following primary TKR (3.3%, 95%CI=3.1,3.5). 90-day mortality rates were lower after UKR compared with TKR (0.08% vs. 0.33%) and lower than predicted had UKR patients received a TKR (0.18%), equivalent to 1 fewer death per 1,000 cases.</p> <p>Conclusions: UKR revision rates were substantially higher than TKR even when demographics and caseload differences were accounted for, however fewer deaths occur after UKR. This should be considered when forming treatment guidelines and commissioning services. Re-revision rates were similar between revised UKRs and TKRs, but considerably higher than for primary TKR, therefore UKR cannot be considered an intermediate procedure.</p>

Cover letter

Submission type: New

Manuscript category: Original article

Title: Patients Receiving A Primary Unicompartmental Knee Replacement Have A Higher Risk Of Revision But A Lower Risk Of Mortality Than Predicted Had They Received A Total Knee Replacement: Data From The National Joint Registry for England, Wales, Northern Ireland and the Isle of Man

As per the ICMJE criteria for authorship

(<http://www.icmje.org/recommendations/browse/roles-and-responsibilities/defining-the-role-of-authors-and-contributors.html>), all seven authors have all contributed in a meaningful way to the study conducted and presented. As requested, we have listed each of the seven authors below, their affiliation and their contribution to the study as per the ICMJE criteria. Given all authors meet the criteria for authorship, we would be grateful if all seven could be listed as authors on the manuscript if you agree to publish the work.

Authors:

- Linda P Hunt ¹: Substantial contributions to the conception/design of the work (including analysis and interpretation of data), drafting the work and revising it critically for important intellectual content, final approval of the version to be published, and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

- Ashley W Blom ¹⁺²: Substantial contributions to the conception/design of the work (including interpretation of data), revising the work critically for important intellectual content, final approval of the version to be published, and agreement to be accountable for

all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

- Gulraj S Matharu ¹: Substantial contributions to the conception/design of the work (including analysis and interpretation of data), drafting the work and revising it critically for important intellectual content, final approval of the version to be published, and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

- Setor K Kunutsor ¹⁺²: Substantial contributions to the conception/design of the work (including analysis and interpretation of data), revising the work critically for important intellectual content, final approval of the version to be published, and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

- Andrew Beswick ¹: Substantial contributions to the conception/design of the work (including analysis and interpretation of data), revising the work critically for important intellectual content, final approval of the version to be published, and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

- J. Mark Wilkinson ³⁺⁴: Substantial contributions to the conception/design of the work (including interpretation of data), revising the work critically for important intellectual content, final approval of the version to be published, and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

- Michael R Whitehouse ¹⁺²: Substantial contributions to the conception/design of the work (including interpretation of data), drafting the work and revising it critically for important intellectual content, final approval of the version to be published, and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Institution:

1. Musculoskeletal Research Unit, Bristol Medical School, University of Bristol, 1st Floor Learning & Research Building, Southmead Hospital, Bristol, BS10 5NB, UK
2. National Institute for Health Research Bristol Biomedical Research Centre, University of Bristol
3. Department of Oncology and Metabolism, The University of Sheffield, Sorby Wing, Northern General Hospital, Sheffield, S5 7AU, UK
4. Centre for Integrated Research into Musculoskeletal Ageing, University of Sheffield

All of the aforementioned authors have actively participated in the study, and the work has not been submitted elsewhere for consideration for publication.

IRB approval: With support under Section 251 of the NHS Act 2006, the Ethics and Confidentiality Committee (ECC), (now the Health Research Authority Confidentiality Advisory Group) allows the NJR to collect patient data where consent is indicated as 'Not Recorded'.

Consent for publication: Before Personal Data and Sensitive Personal Data is recorded, express written patient consent is provided. The NJR records patient consent as either 'Yes', 'No', or 'Not Recorded'.

Availability of data and material: Access to data is available from the National Joint Registry for England and Wales, Northern Ireland and the Isle of Man, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data access applications can be made to the National Joint Registry Research Committee. Access to linked HES and PROMs data is available through data applications to NHS Digital.

27th July 2020

Response to reviewer comments Re: Manuscript # JOA-D-20-00941 "Patients Receiving A Primary Unicompartmental Knee Replacement Have A Higher Risk Of Revision But A Lower Risk Of Mortality Than Predicted Had They Received A Total Knee Replacement: Data From The National Joint Registry for England, Wales, Northern Ireland and the Isle of Man"

Many thanks for reviewing our work. We appreciate all the comments received and feel that these have helped improve our paper. All responses to the reviewer comments below are provided in **bold text**, and we have cited both page number and line number for any changes made in the manuscript. As requested we have only submitted a clean copy of the main text document.

Reviewer #1: I very much enjoyed reading this manuscript and feel that it represents a new vantage point on an old discussion.

Thanks for your positive comments. No specific comments to address.

I feel the authors use of modeling here was very appropriate.

No specific comments to address.

I do have some suggestions to hopefully make this more accessible to the reader that I would like to see implemented prior to acceptance.

1. In either the introduction or the discussion there should be some mention of why the use of a predictive model is necessary. The authors good site the need to adjust for the younger age, higher BMI, and a higher proportion of male subjects in unicondylar arthroplasty group. **The last paragraph of the Introduction (page 3, lines 49-52) lists the study aims, number (2) of which states ‘estimate what the risk-adjusted revision rates would have been for UKR patients had they received a TKR, estimating any excess revisions’. We have added a sentence at the end of this paragraph to indicate that a prediction model needs to be developed to facilitate this (page 3, lines 52-54).**

2. In the methods and results section the author's spend quite a bit of space describing how they chose the most important variables in their adjustment and model. I think that this section could be shortened substantially by referring to the type of model that was used, a reference for that model and testament to where it has been used before, and then simply stating what variables were used for adjustment.

We wish to keep details of the modelling process in the paper. Although the Flexible Parametric Models have been used in different settings, the specific model building for this particular application has not been documented elsewhere. Anyone wanting to repeat our work, therefore, would need this level of granular detail to do so.

We suggest keeping the Statistical Methods section as it stands but moving the modelling details in the Results to a “Supplementary Information” section which we have now done. In this way, the interested reader can refer to this section as needed, without being distracted from the main message of the paper. This also reduces the text of the main manuscript as recommended by both reviewers. We therefore have moved some of the results section to the section headed “Supplementary Information.”

Note this section also contains the (briefer) details of how the mortality predictor was modelled (moved out of the Mortality section, again to reduce text of the main

manuscript).

3. Results. In the results section I think the authors should lead off by stating the results present in table 3 which I think is the most important take home message of the article. Again the description of the modeling can be reduced in this results section.

See also our response to point 2 above regarding the reduction of the text related to modelling.

Figure 1 has been removed and replaced by the old Figure 2 (new Figure 1)

The reference to Table 3 has been moved to the first paragraph at top of section headed 'Predictive model for cumulative risk of revision'. We have not put Table 3 any earlier, as its important to describe briefly the demographics of the cohort we are analysing before presenting Table 3.

While I understand the author's point, the referencing of the results surgical volume is also somewhat confusing. Perhaps just comparing "apples to apples" and reporting the high-volume TKR results versus the high-volume UKR results. Then as a secondary statement to drive the point home they could mention the high-volume UKR results versus the lowest volume TKR results.

(Old) Figures 3a/3b have been removed as per your request below. We have also simplified the Effect of Caseload section as requested (page 8, lines 144-153).

The authors report the percentage of cases that were cemented versus cementless total knee replacements. Is there any data available on fixed versus mobile bearing unicondylar replacements and their distribution within the data set? This would be very helpful to critics who would note substantial differences in revision rates between fixed and mobile bearing UKA.

We have now clarified the percentage of fixed and mobile UKR bearings in the revised manuscript (page 6, lines 106-107).

4. Figures. I think in general there are some redundant figures. For instance I am not certain what information figure 1 supplies that figure 2 does not supply. Furthermore the information contained in figure 3 is well illustrated by the table addressing surgical volumes and I think is probably unnecessary.

We have removed our original Figure 1 and Figure 3 and relabelled the other Figures appropriately. Our previous Figure 2 is now Figure 1

In figure 4 unless I am misunderstanding with a figure of the number of revised total knee replacements was higher than the number of revised unicondylar knee replacements. Is also not quite clear how prediction was used and coming up with these numbers.

We have now revised the text in the "Risk of re-revision following revision of primary TKR or UKR" to try to clarify this (page 8-9, lines 155-173).

We have removed the old Figure 4 as the prediction 'dashed' curves had been included in the old Figure 5 (in the same way that the old Figure 2 included the curves from the old Figure 1). Our original Figure 5 is our now the new Figure 2. We hope that the new figures accompanied by the changes in the manuscript provide clearer information for the readers.

Overall I think this represents an important contribution.

Thank you. No specific comments to address.

Reviewer #3: This is a review of manuscript JOA-D-20-00941 "Patients Receiving A Primary Unicompartamental Knee Replacement Have A HigherRisk Of Revision But A Lower Risk Of Mortality Than Predicted Had They Received A Total Knee Replacement: Data From The National Joint Registry for England, Wales, Northern Ireland and the Isle of Man". There were 926,542 cases; 83,746 (9.0%) were primary UKRs and 842,796 (91.0%) primary TKRs. The 90% 'training set' included 758,516 TKRs, and the 'test set' 84,280 TKRs. A 90% random sample of primary TKRs was identified as a 'training set' and used to derive a prediction model for the cumulative risk of revision, based on age, gender, ASA grade and year of primary. The model was used to make predictions for the UKRs and validated with the remaining 10% ('test set') of TKRs.

No specific comments to address.

The study aims were to: (1) determine comparative revision rates, (2) estimate what the risk-adjusted revision rates would have been for UKR patients had they received a TKR, estimating any excess revisions, (3) determine the re-revision rates for failed primary UKR and TKR and (4) determine the 90-day mortality rates.

No specific comments to address.

The conclusions were "UKR revision rates were substantially higher than TKR even when demographics and caseload differences were accounted for, however fewer deaths occur after UKR. This should be considered when forming treatment guidelines and commissioning services. Re-revision rates were similar between revised UKRs and TKRs, but considerably higher than for primary TKR, therefore UKR cannot be considered an intermediate procedure."

No specific comments to address.

The data was prospectively collected and retrospectively reviewed with large numbers from a respected registry. I believe the statistical methods are solid, the manuscript is to the point, and the conclusions are valid. My only issue with the manuscript is its length. Too many figures for print. While graphics can be very helpful, some in this manuscript are not (fig 3a). If the manuscript cannot be paired to a shorter length then I would recommend acceptance as an on-line publication. If able to be shortened, I would recommend print publication.

Our original Fig 1, Fig 3a/b and Fig 4 have been removed. We are therefore using half the figures we used in the initial submission. We have made a number of deletions from the text to remove text from the manuscript which includes moving some of the modelling detail to a Supplementary section as detailed above. We have left our supplementary Tables and Figures as they are, given this information is usually only available online (and not in print) so can be referred to by readers as they so wish.

Editor Comments:

Authors need to address queries and incorporate concerns, then paper will be accepted.

We have addressed all the reviewers' comments as detailed above. However please do let us know if you would like any further changes to the manuscript.

[Click here to access/download](#)

**Conflict of Interest Statement, Combined for All Authors
(Blinded - no signatures or names)**

Col Blinded.doc

[Click here to access/download](#)

Conflict of Interest Statement (1 for each author)
Col AB.doc

[Click here to access/download](#)

Conflict of Interest Statement (1 for each author)
Col ABes.doc

[Click here to access/download](#)

Conflict of Interest Statement (1 for each author)
Col GM.doc

[Click here to access/download](#)

Conflict of Interest Statement (1 for each author)
Col JMW.doc

[Click here to access/download](#)

Conflict of Interest Statement (1 for each author)
Col LH.doc

[Click here to access/download](#)

Conflict of Interest Statement (1 for each author)
Col MW.doc

[Click here to access/download](#)

Conflict of Interest Statement (1 for each author)
Col SK.doc

**Patients Receiving A Primary Unicompartmental Knee Replacement Have A Higher Risk Of
Revision But A Lower Risk Of Mortality Than Predicted Had They Received A Total Knee
Replacement: Data From The National Joint Registry for England, Wales, Northern Ireland
and the Isle of Man**

Linda P Hunt PhD MSc BSc Senior Research Fellow ¹

Ashley W Blom PhD MD FRCS FRCS(Tr&Orth) Professor of Orthopaedic Surgery and Head of Translational
Health Sciences ¹⁺²

Gulraj S Matharu BSc(Hons), MRCS, MRes, DPhil Clinical Lecturer in Trauma and Orthopaedic Surgery ¹

Setor K Kunutsor BA MB ChB MA PhD Research Fellow in Evidence Synthesis ¹⁺²

Andrew Beswick BSc Research Fellow in Evidence Synthesis ¹

J. Mark Wilkinson PhD FRCS(Tr&Orth) Professor of Orthopaedics ³⁺⁴

Michael R Whitehouse PhD MSc BSc FRCS(Tr&Orth) Reader and Consultant in Trauma & Orthopaedics ¹⁺²

Affiliations

1. Musculoskeletal Research Unit, Bristol Medical School, University of Bristol, 1st Floor Learning & Research Building, Southmead Hospital, Bristol, BS10 5NB, UK
2. National Institute for Health Research Bristol Biomedical Research Centre, University of Bristol
3. Department of Oncology and Metabolism, The University of Sheffield, Sorby Wing, Northern General Hospital, Sheffield, S5 7AU, UK
4. Centre for Integrated Research into Musculoskeletal Ageing, University of Sheffield

Corresponding author:

Name: Gulraj Matharu

Address: As stated above

Email: gsm@doctors.org.uk

Tel: +44 (0) 7949 921545 Fax: not available

Contribution of authors:

The study design was conceived and developed by LPH, AWB and MRW. LPH and MRW conducted the primary analysis. All authors contributed to interpretation of the data. LPH, AWB, GSM, SKK, AB and MRW drafted the manuscript. The final manuscript was edited and approved by all authors. All authors agree to be accountable for all aspects of the work.

Funding:

This article presents independent research funded by the Healthcare Quality Improvement Partnership, National Joint Registry and by grant 20894 from Arthritis Research UK. This study was supported by the NIHR Biomedical Research Centre at the University Hospitals Bristol NHS Foundation Trust and the University of Bristol. The views expressed in this publication are those of the author(s) and not necessarily those of the NHS, the National Institute for Health Research or the Department of Health and Social Care. The funder had no role in the design of the study and collection, analysis, and interpretation of data and in writing the manuscript beyond the contribution of the listed co-authors.

Acknowledgments:

We thank the patients and staff of all of the hospitals who have contributed data to the National Joint Registry. We are grateful to the Healthcare Quality Improvement Partnership, the National Joint Registry Steering Committee, and the staff at the National Joint Registry for facilitating this work. The views expressed represent those of the authors and do not necessarily reflect those of the National Joint Registry Steering Committee or Healthcare Quality Improvement Partnership, who do not vouch for how the information is presented.

Patients Receiving A Primary Unicompartmental Knee Replacement Have A Higher Risk Of Revision But A Lower Risk Of Mortality Than Predicted Had They Received A Total Knee Replacement: Data From The National Joint Registry for England, Wales, Northern Ireland and the Isle of Man

Abstract

Background: To determine unicompartmental (UKR) and total knee replacement (TKR) revision rates, compare UKR revision rates with what they would have been had they received TKR instead, subsequent re-revision and 90-day mortality rates.

Methods: Using National Joint Registry data, we estimated UKR and TKR revision and mortality rates. Flexible Parametric Survival modelling (FPM) was used to model failure in TKR and make estimates for UKR. Kaplan-Meier estimates were used to compare cumulative re-revision for revised UKRs and TKRs.

Results: 10-year UKR revision rates were 2.5-times higher than expected from TKR, equivalent to 70 excess revisions/1,000 cases within 10-years (5,861 excess revisions in this cohort). Revision rates were 2.5 times higher for the highest quartile volume UKR surgeons compared to the same quartile for TKR, and 3.9 times higher for the lowest quartiles respectively. Re-revision rates of revised TKRs (10-years=17.5%; 95%CI=16.4,18.7) were similar to revised UKRs (15.2%; 95%CI=13.4,17.1) and higher than revision rates following primary TKR (3.3%, 95%CI=3.1,3.5). 90-day mortality rates were lower after UKR compared with TKR (0.08% vs. 0.33%) and lower than predicted had UKR patients received a TKR (0.18%), equivalent to 1 fewer death per 1,000 cases.

25

26 **Conclusions:** UKR revision rates were substantially higher than TKR even when
27 demographics and caseload differences were accounted for, however fewer deaths occur
28 after UKR. This should be considered when forming treatment guidelines and
29 commissioning services. Re-revision rates were similar between revised UKRs and TKRs, but
30 considerably higher than for primary TKR, therefore UKR cannot be considered an
31 intermediate procedure.

32

33 **Key words:**

34 outcomes; mortality; revision rates; total knee replacement; unicompartmental knee

INTRODUCTION

Knee replacement is a clinically effective intervention for end-stage knee osteoarthritis. Unicompartamental knee replacement (UKR) is an alternative to total (TKR); up to 50% of patients may be considered eligible.¹ Although not all patients eligible for TKR would be for UKR, all patients who are suitable for UKR could receive TKR.

Earlier randomised controlled trials (RCTs) suggested UKR provided better postoperative function with fewer complications, but was associated with more revisions up to five years, but no difference in the longer-term.^{2,3} The largest recent RCT concluded that interventions have similar clinical outcomes at 5-years.⁴ Observational studies have shown an increased risk of revision for UKR,^{5,6} lower risk of mortality,^{7,8} with either slightly improved⁹ or equivalent^{10,11} patient reported outcomes. Little is known about the comparative risk of re-revision.¹²

The study aims were to: (1) determine comparative revision rates, (2) estimate what the revision rates would have been for UKR patients had they received a TKR, estimating any excess revisions, (3) determine the re-revision rates for failed primary UKR and TKR and (4) determine the 90-day mortality rates. To facilitate aim (2), we sought a prediction model for outcome in TKRs, from predictors related to outcome (e.g. age and gender) that were distributed differently in UKRs, and used the derived model to predict outcome in UKR.

PATIENTS AND METHODS

Data Source and Population

We analysed prospectively collected observational data from the National Joint Registry on all primary knee replacements. Data entered between 1st April 2003 and 31st December 2016 was considered (n=975,739).⁵ Unique patient identifiers were used to link primary to revision procedure (implant added, removed or exchanged) and date of death where relevant (Personal Demographics Service).

Exclusions were uncertain knee type (n=45), indication other than osteoarthritis (n=37,388), and patellofemoral replacement (n=11,764). For age or gender analyses, those with missing/non-verifiable values were excluded. American Society of Anaesthesiologists (ASA) grade was known for all cases. Later analyses involving body mass index (BMI) excluded those with BMI <10 or >60kg/m², regarded as probably inaccurate.⁷

The primary exposure was UKR or TKR and the primary outcome was revision surgery of the primary. Secondary outcomes were mortality, estimates of the number of excess revisions, and re-revision rates.

Statistical Methods

A 90% random sample of primary TKRs was identified as a 'training set' and used to derive a prediction model for the cumulative risk of revision, based on age, gender, ASA grade and year of primary (see below).¹³ The model was used to make predictions for the UKRs and validated with the remaining 10% ('test set') of TKRs.

78

79 We used survival analysis to derive a prediction model in the training set for the time to first
80 revision, censoring at 31st December 2016, or death. We used Flexible Parametric Survival
81 Models (FPMs),^{14,15} as implemented in Stata.¹⁶ These can accommodate predictor variable
82 time-varying effects, assessed using likelihood ratio tests and examination of the Akaike and
83 Bayesian information criteria. Predictor variables were: (a) male gender, (b) age at primary,
84 (c) ASA grade [P1; P2; P3; P4-5], (d) year of primary and, where available (e) BMI class
85 ['underweight' <19kg/m²; 'normal' 19-25kg/m²; 'overweight' 26-30kg/m²;
86 'obese' >30kg/m²].

87

88 For mortality, FPM was used to model time to death, censoring at 90 days or 31st December
89 2016, excluding bilateral simultaneous procedures. The same predictors were used, and
90 exploratory analyses conducted including quintiles of area deprivation (IMD for recipients
91 with linkable HES records),¹⁷ as close as possible to the date of the primary, and BMI class.

RESULTS

After exclusions, there were 926,542 cases; 83,746 (9.0%) were primary UKRs and 842,796 (91.0%) primary TKRs. The 90% 'training set' included 758,516 TKRs, and the 'test set' 84,280 TKRs.

Six of the 926,542 cases had missing age, 164 unverifiable age and 2 uncertain gender. These were excluded from age and gender analyses respectively. BMI was known/in range for 542,630 (59%; 0.5% of BMIs were 'out of range'). BMI was not recorded in the early years of registry but became progressively more complete with time.

Patients undergoing UKR tended to be younger, a higher proportion were male (Table 1), and were less likely to be obese; factors shown to influence the risk of revision.^{18,19} Cemented TKR implants were more common amongst older patients and slightly more common in females (Table 2). Of the UKRs, 32.7% (n=27,403) were fixed bearing designs and 66.3% (n=55,480) were mobile bearings, bearing mobility was not known in 1.0% of UKRs.

Univariable analysis revealed clear relationships with ASA grade (Supplementary Figure i), BMI (Supplementary Figure ii) and year of implantation (Supplementary Figure iii) as expected. Higher risk of revision was seen in lower ASA grades (reflecting increased life expectancy in these groups and the healthy patient selection effect) and higher BMI classes. The cumulative risk of revision increased until 2008 and then declined.

Predictive model for cumulative risk of revision

A prediction model for cumulative revision risk was developed in the 90% ‘training sample’ of TKRs using gender, age, ASA and year of the primary (n=758,376 with complete information); details of modelling steps are given in the “Supplementary Information” section. The model was used to make out-of-sample predictions for the ‘test’ set of TKRs, UKRs and the predictions were compared to the respective, observed cumulative revision rates (Kaplan-Meier estimates, with pointwise 95% confidence intervals (CIs)) (Figure 1, Table 3).

If the patients who received UKR had instead received a TKR, we would have expected their cumulative revision risk to be higher than for the cases that received a TKR, reflecting their younger age and higher proportion of males. The ‘dashed’ lines (predicted results) illustrate this. The ‘solid lines’ in Figure 1 are the observed rates, which for the TKR ‘test’ set were close to the predicted rates, thus validating the model. For the UKRs, however, the observed rates were substantially higher than predicted had they received a TKR instead (at 10-years: 11.4% vs. 4.4%, Table 3). For every 100 UKRs performed, we estimated 7 extra revisions within 10 years compared to what would have occurred if they had received a TKR, equating to 5,861 excess revisions in our cohort.

A sensitivity analysis performed with the inclusion of available BMI class as a predictor in the training set (n=441,991) did not significantly change the results of the analysis (Supplementary Figure vi, vii, Supplementary Table i).

Effect of caseload

Different surgeon caseloads for TKRs and UKRs may impact outcome. To compare caseload between TKR and UKR we divided each group into quartiles based on the number of primary knee replacements of that type that the consultant surgeon in charge had performed during the previous 12-months.

Within both the TKR and UKR groups, revision rates were significantly lower with higher caseload (Table 4; logrank tests: $P < 0.001$ for both). Within corresponding quartiles, however, the revision rates were always higher with UKR than with TKR, ranging from 2.5 times higher revision rates for UKR compared to TKR in the highest caseload volume quartiles, to 3.9 times higher in the lowest caseload volume quartiles. The 10-year revision rate for the highest volume UKR surgeons (performing 100 to 440 UKRs annually) was 2.1 times higher than the lowest volume TKR surgeons (performing up to 36 TKRs annually) (7.6% vs. 3.6%). Furthermore, returning to our prediction model, the UKRs performed by the highest volume surgeons (100-440) still did worse than would have been predicted from the training set of (all) TKRs (7.6% compared with 4.1% predicted).

Risk of re-revision following revision of primary TKR or UKR

The number of re-revisions following revision of a primary TKR ($n=842,796$) and UKR ($n=83,746$) were explored. There were 16,782 TKR revisions, with 1,701 re-revised and 5,383 UKR revisions, with 476 re-revised.

We analysed the rates of revision in the 'test' set ($n=84,280$) TKRs, described above, compared to the rates of re-revision for revised TKRs and UKRs. The prediction model for (first) revision derived from the TKR training set using age, gender and year of (primary)

operation (n=758,376 with complete information) was reapplied to the 'test' set (84,267 cases with complete information) and then applied to both revised TKRs and revised UKRs to estimate what the re-revision rates would have been had the processes been the same. Updated values of age, ASA grade and year of operation were used for the 'prediction'. The predicted revision rates were compared to those actually observed (Kaplan-Meier) (Figure 2 and Table 5). The rates of re-revision for the revised cases were higher than they were for the primary TKR cases. Re-revision rates of revised TKRs (17.5% at 10-years; 95%CI=16.4,18.7) were similar to revised UKRs (15.2%; 95%CI=13.4,17.1). Both were much higher compared with revision rates following primary TKR (3.3%, 95%CI=3.1,3.5). Sensitivity analysis were performed with the addition of BMI class to the model (Supplementary Figure vii) and restricting to single stage revisions (results not shown), neither changed the results.

Mortality

This analysis excluded bilateral procedures (14,038 or 1.7% TKRs; 5,047 or 6.0% UKRs). Univariate analysis of the remainder confirmed lower cumulative mortality up to 90 days for the 78,699 UKRs than the 828,758 TKRs (Figure 3; logrank, $P<0.001$).

A prediction model developed from the TKR training set (n=745,803) using gender, age, ASA and year of primary ("Supplementary Information" section) predicted 90-day mortality well in the remaining 82,805 'test set' of TKRs (actual rate of 0.33% (95%CI=0.29,0.37) vs. 0.32% predicted) whereas that predicted for the 78,681 UKRs was much higher (actual 0.08% (95%CI=0.06,0.11) vs. 0.18% predicted had they received a TKR). Thus if the 78,681 UKRs had had a TKR instead and selection is fully accounted for,¹⁷ we might have expected 78

186 excess 90-day deaths (142 rather than the observed 64). Results were similar with area of
187 deprivation and BMI class added to the model (results not shown).

DISCUSSION

Revision rates for UKR patients were substantially higher than predicted if patients had undergone TKR, equating to 70 excess revisions per 1,000 cases by 10-years, despite consideration of different patient demographics and surgeon caseload, however fewer deaths occurred after UKR, equating to 1 fewer death per 1,000 cases. Rates of re-revision were similar for revised UKRs and revised TKRs, both of which were much higher than the risk of revision following primary TKR.

UKR and TKR are widely used contemporary alternatives for treating knee osteoarthritis. Whilst not every patient that receives a TKR would be suitable for a UKR, every patient receiving a UKR could have undergone TKR instead. Our results support observational data that the revision rate is between two- and three-times higher for UKR than TKR.^{5,8,20} There are differences between patients receiving UKR and TKR that influence the risk of revision (e.g. age and gender),¹⁸ hence crude comparison of revision rates is not justified. When these variables were accounted for, the increased risk of revision for UKR (by 2.5-times) persisted. Our data suggest that if all patients had received TKR instead of UKR, approximately 5,861 excess revisions could have been avoided. This represents a substantial healthcare burden given revisions are costly (£15,900/case),²¹ technically challenging, with a substantial risk of morbidity and less predictable PROMs.²² The recently reported TOPKAT trial found similar revision rates for UKR and TKR at 5-years, around 4%,⁴ which is higher than the 10-year revision rates observed for TKR in even the lowest volume quartile surgeons in our analysis. This may be due to the TOPKAT trial not being powered to detect a difference in revision rates, the expertise based selection of surgeons to the trial or it may be that patients with isolated medial compartment OA that undergo TKR are at higher risk

of revision than those with more widespread disease, although we do not have a biologically plausible explanation for this.

Previous work shows that increasing caseload is associated with lower revision rates following primary UKR, and to a lesser degree following primary TKR,²³ leading to recommendations that surgeons should increase UKR caseload to improve outcomes.²⁴ Our findings also show increasing caseload was associated with lower revision rates following both primary UKR and primary TKR, however, the revision rate was always significantly higher with UKR compared with TKR for the respective quartile of caseload; ranging from 3.9 times higher with UKR in the lowest quartile, to 2.5 times higher in the highest quartile. The 10-year revision rate for the highest volume UKR surgeons was more than twice that of the lowest volume TKR surgeons. The effect of an individual surgeon changing their caseload is unknown, therefore we have concerns with encouraging surgeons to increase their UKR caseload, when for most surgeons their UKR revision rate is likely to be higher than for TKRs.

There are proposed potential benefits for UKR; the procedure is quicker, is less invasive, the inpatient stay is shorter,^{8,25} the mortality is lower^{7,8} and it is proposed that PROMs may be better,¹⁰ associated health costs lower²⁶ and that a UKR can be revised to a TKR that will then perform the same as a primary TKR,²⁷ hence UKR having a potential role as an intermediate procedure. We did observe lower short-term mortality rates with UKR compared with TKR, which agrees with previous observations.^{7,8} The observed mortality for patients receiving a UKR, being lower than that predicted had they received a TKR, may

suggest unaccounted selection bias for these procedures, with a different baseline mortality risk profile.¹⁷

Differences in PROMs between UKR and TKR are not consistent in the literature. Evidence synthesis has shown small, non-significant, differences in PROMs,³ with analysis of NJR PROMs data showing statistically significant differences in outcomes that are below the minimal clinically important difference (MCID).¹⁰ Early RCT data showed improved short-term PROMs in UKR,⁹ but the largest and best designed RCT (TOPKAT) recently observed no difference in 5-year PROMs.⁴

There is variance in reported re-revision outcomes. Some suggest the UKR re-revision rate is consistent with the revision rate of primary TKR,²⁷ however a recent study of the Danish Registry showed similar re-revision for revised UKRs and TKRs but a three-fold higher risk of revision for a UKR converted to TKR compared to a primary TKR.¹² Evidence synthesis shows that revision of UKR compared to primary TKR has longer operation times, involves more complex operations, higher revision rates and worse clinical outcomes.²⁸ Our outcomes are generally consistent with these observations. The data generated by a combination of evidence synthesis and large comprehensive registry analysis is subject to less bias than single-centre case series, therefore revision of UKR should be considered to be similar to revision of TKR, and not primary TKR.

9% of the cases in our analysis were UKRs, consistent with the current rates reported in the NJR.⁵ Our patients are similar in age, diagnosis, BMI and gender to most registries and the implants used are similar, our results are thus likely to be generalizable. Comparing crude

UKR and TKR failure rates would not be valid due to variation in age and gender, which are on the causal pathway of failure of knee replacement. The NJR represents the largest joint registry in the world and provides contemporary, real world evidence of outcomes following joint replacement. Data capture rates are over 95%.⁵ Other strengths of this study include long-term follow-up and the utilization of advanced modelling that can address the variation between groups. Our model is validated by its accurate prediction of the actual failure in the TKR test set and thus the UKR predictions are likely to be correct.

Using observational data means causality cannot be determined. Revision rates can be underestimated in the NJR, although there is no reason to suspect any underreporting would differ between the groups. PROMs were not assessed, nor were non-revision procedures (i.e. wound washouts and fracture fixation), or complications not requiring further surgery (i.e. conservatively treated fractures or infections), which are all important to consider when comparing results between treatments.

In conclusion UKR revision rates were substantially higher than TKR irrespective of patient demographics and surgical caseload, although UKRs had a lower mortality. Re-revision rates were similar between revised UKRs and TKRs, and considerably higher than primary TKR revision rates, we therefore recommend that UKR cannot be considered an intermediate procedure. The risk of both revision and re-revision following a UKR, as well as the potential advantages of UKR, need to be fully considered when clinical decisions are made by patients and surgeons, when clinical guidelines are produced, and when commissioning decisions are made.

References

1. **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. *Knee* 2009;16(6):473–478.
2. **Zhang Q, Zhang Q, Guo W, Guo W, Zhang Q, Sun R, et al.** Comparison of unicompartmental knee arthroplasty and total knee arthroplasty in the treatment of unicompartmental osteoarthritis. *Curr Orthop Pract* 2010;21(5):497–503.
3. **Arirachakaran A, Choowit P, Putananon C, Muangsiri S, Kongtharvonskul J.** Is unicompartmental knee arthroplasty (UKA) superior to total knee arthroplasty (TKA)? A systematic review and meta-analysis of randomized controlled trial. *Eur J Orthop Surg Traumatol* 2015;25(5):799–806.
4. **Beard DJ, Davies LJ, Cook JA, MacLennan G, Price A, Kent S, et al.** The clinical and cost-effectiveness of total versus partial knee replacement in patients with medial compartment osteoarthritis (TOPKAT): 5-year outcomes of a randomised controlled trial. *Lancet* 2019;394(10200):746–756.
5. **NJR Steering Committee.** National Joint Registry for England, Wales, Northern Ireland and the Isle of Man: 14th Annual Report. njrcentre.org.uk. 2017 Sep:1–202.
6. **Chawla H, van der List JP, Christ AB, Sobrero MR, Zuiderbaan HA, Pearle AD.** Annual revision rates of partial versus total knee arthroplasty: A comparative meta-analysis. *Knee* 2017;24(2):179–190.

- 303 7. **Hunt LP, Ben-Shlomo Y, Clark EM, Dieppe P, Judge A, MacGregor AJ, et al.** 45-day
304 mortality after 467,779 knee replacements for osteoarthritis from the National Joint
305 Registry for England and Wales: an observational study. *Lancet*
306 2014;384(9952):1429–1436.
- 307 8. **Liddle AD, Judge A, Pandit H, Murray DW.** Adverse outcomes after total and
308 unicompartmental knee replacement in 101 330 matched patients: a study of data
309 from the National Joint Registry for England and Wales. *Lancet* 2014;384(9952):1437–
310 1445.
- 311 9. **Burn E, Sanchez-Santos MT, Pandit HG, Hamilton TW, Liddle AD, Murray DW, et al.**
312 Ten-year patient-reported outcomes following total and minimally invasive
313 unicompartmental knee arthroplasty: a propensity score-matched cohort analysis.
314 *Knee Surg Sports Traumatol Arthr* 2018;26(5):1455–1464.
- 315 10. **Liddle AD, Pandit H, Judge A, Murray DW.** Patient-reported outcomes after total and
316 unicompartmental knee arthroplasty a study of 14,076 matched patients from the
317 National Joint Registry for England and Wales. *Bone Joint J* 2015;97-B(6):793–801.
- 318 11. **Horikawa A, Miyakoshi N, Shimada Y, Kodama H.** Comparison of clinical outcomes
319 between total knee arthroplasty and unicompartmental knee arthroplasty for
320 osteoarthritis of the knee. *J Orthop Surg Res* 2015;10(1):168.
- 321 12. **El-Galaly A, Kappel A, Nielsen PT, Jensen SL.** Revision Risk for Total Knee Arthroplasty
322 Converted from Medial Unicompartmental Knee Arthroplasty: Comparison with
323 Primary and Revision Arthroplasties, Based on Mid-Term Results from the Danish
324 Knee Arthroplasty Registry. *J Bone Joint Surg Am* 2019;101(22):1999–2006.

- 325 13. **Hunt LP, Whitehouse MR, Beswick A, Porter ML, Howard P, Blom AW.** Implications
326 of Introducing New Technology: Comparative Survivorship Modeling of Metal-on-
327 Metal Hip Replacements and Contemporary Alternatives in the National Joint Registry.
328 *J Bone Joint Surg Am* 2018;100(3):189–196.
- 329 14. **Royston P, Parmar MKB.** Flexible parametric proportional-hazards and proportional-
330 odds models for censored survival data, with application to prognostic modelling and
331 estimation of treatment effects. *Stat Med* 2002;21(15):2175–2197.
- 332 15. **Lambert PC, Royston P.** Further development of flexible parametric models for
333 survival analysis. *SJ* 2009;9(2):265–290.
- 334 16. **Royston P, Lambert PC.** *Flexible Parametric Survival Analysis Using Stata: Beyond the*
335 *Cox Model*. Stata Press, 2011.
- 336 17. **Hunt LP, Whitehouse MR, Howard PW, Ben-Shlomo Y, Blom AW.** Using long term
337 mortality to determine which perioperative risk factors of mortality following hip and
338 knee replacement may be causal. *Sci Rep* 2018;8(1):15026.
- 339 18. **Bayliss LE, Culliford D, Monk AP, Glyn-Jones S, Prieto-Alhambra D, Judge A, et al.**
340 The effect of patient age at intervention on risk of implant revision after total
341 replacement of the hip or knee: a population-based cohort study. *Lancet*
342 2017;389(10077):1424–1430.
- 343 19. **Culliford D, Maskell J, Judge A, Arden NK, COAST Study Group.** A population-based
344 survival analysis describing the association of body mass index on time to revision for

- 345 total hip and knee replacements: results from the UK general practice research
346 database. *BMJ Open* 2013;3(11):e003614.
- 347 20. **Chawla H, van der List JP, Christ AB, Sobrero MR, Zuiderbaan HA, Pearle AD.** Annual
348 revision rates of partial versus total knee arthroplasty: A comparative meta-analysis.
349 *Knee* 2017;24(2):179–190.
- 350 21. **Kallala RF, Vanhegan IS, Ibrahim MS, Sarmah S, Haddad FS.** Financial analysis of
351 revision knee surgery based on NHS tariffs and hospital costs: does it pay to provide a
352 revision service? *Bone Joint J* 2015;97-B(2):197–201.
- 353 22. **Greidanus NV, Peterson RC, Masri BA, Garbuz DS.** Quality of life outcomes in revision
354 versus primary total knee arthroplasty. *J Arthroplasty* 2011;26(4):615–620.
- 355 23. **Liddle AD, Pandit H, Judge A, Murray DW.** Effect of Surgical Caseload on Revision
356 Rate Following Total and Unicompartmental Knee Replacement. *J Bone Joint Surg Am*
357 2016;98(1):1–8.
- 358 24. **Liddle AD, Pandit H, Judge A, Murray DW.** Optimal usage of unicompartmental knee
359 arthroplasty a study of 41 986 cases from the National Joint Registry for England and
360 Wales. *Bone Joint J* 2015;97-B(11):1506–1511.
- 361 25. **Lombardi AV Jr, Berend KR, Walter CA, Aziz-Jacobo J, Cheney NA.** Is Recovery Faster
362 for Mobile-bearing Unicompartmental than Total Knee Arthroplasty? *Clin Orthop*
363 *Relat Res* 2009;467(6):1450–1457.
- 364 26. **Burn E, Liddle AD, Hamilton TW, Judge A, Pandit HG, Murray DW, et al.** Cost-
365 effectiveness of unicompartmental compared with total knee replacement: a

- 366 population-based study using data from the National Joint Registry for England and
367 Wales. *BMJ Open* 2018;8(4):e020977.
- 368 27. **Lombardi AV, Kolich MT, Berend KR, Morris MJ, Crawford DA, Adams JB.** Revision of
369 Unicompartmental Knee Arthroplasty to Total Knee Arthroplasty: Is It as Good as a
370 Primary Result? *J Arthroplasty* 2018;33(7S):S105–S108.
- 371 28. **Lee JK, Kim HJ, Park JO, Yang J-H.** Inferior outcome of revision of unicompartmental
372 knee arthroplasty to total knee arthroplasty compared with primary total knee
373 arthroplasty. *Knee Surg Sports Traumatol Arthr* 2018;31:339.

Figure legends

Figure 1: Comparison between actual (Kaplan-Meier, with pointwise 95%CI) and model predicted cumulative % revision for the 'test' set of TKRs (n=84,267) and UKRs (n=83,727).

Figure 2: Comparison between actual (Kaplan-Meier, with pointwise 95%CI) and model predicted cumulative revision for the 'test' set of primary TKRs (n=84,267) compared to revised TKRs (n=16,782) and revised UKRs (n=5,383).

Figure 3: Cumulative % mortality up to 90 days for unilateral primary TKRs (n=828,758) and UKRs (n=78,699)

Supplementary figure legends

Supplementary Figure i: Estimated cumulative percentage probability of revision (Kaplan-Meier) by ASA grade for primary TKR plus UKR

Supplementary Figure ii: Estimated cumulative percentage probability of revision (Kaplan-Meier) by BMI class for primary TKR plus UKR

Supplementary Figure iii: Estimated cumulative percentage probability of revision (Kaplan-Meier) by year of primary operation for primary TKR plus UKR

Supplementary Figure iv: Smoothed estimates of the hazard rates of revision by time from primary TKR operation (years) for males and females aged <55, 55-64, 65-74, 75+ years at primary operation (note: estimates at the right hand side of these curves are less likely to be reliable as fewer patients remained at risk).

A. Males

B. Females

Supplementary Figure v: Fit of the FPM using gender and age in the 'training' set of total knee replacements

A. Model estimated hazard rates (left hand side) and cumulative revision (right hand side) for males and females aged 60, 70 and 80 years at primary

B. Comparison between the model estimated survival and observed survival (Kaplan-Meier estimates) for males and females aged <55, 55-64, 65-74, 75+ years at primary.

408 Model estimated values are shown as respective black lines (short dashed, medium
409 dashed, long dashed and solid lines)

410

411 **Supplementary Figure vi:** Sensitivity analysis of model-predicted cumulative percentage
412 revision for the 'test' set of TKRs (n=48,922) and UKRs (n=51,605) where age, gender and
413 BMI group at primary operation is known.

414

415 **Supplementary Figure vii:** Sensitivity analysis of comparison between actual and model
416 predicted cumulative percentage revision for the 'test' set of TKRs (n=48,922) and UKRs
417 (n=51,605) where age, gender and BMI group at primary operation is known.

TKR (test set): Predicted ———— Observed ————
UKR: Predicted ———— Observed ————

Figure 2

[Click here to access/download;Figures \(Number each one\);Fig2.tif](#)

Figure 3

Number at risk

P1	115120	105049	94438	84041	74820	65353	56028	46935	37714	28757	20333
P2	670347	593962	516676	441384	374212	308704	248072	192779	142105	96009	58317
P3	138077	118945	100877	83701	68975	55295	43012	32231	22959	15433	9218
P4/P5	2998	2550	2205	1865	1547	1256	1018	804	618	455	289

Number at risk

Normal	83204	71223	59527	48082	38442	29635	21984	15220	9434	4695	2570
Obese	254329	215175	177263	141676	111747	84206	60250	40097	23063	10088	5293
Overweight	203780	173575	144486	116425	93001	71397	52224	35683	21405	9940	5409
Underweight	1317	1148	987	811	653	525	363	251	169	86	42

- - - Male 60y
 — Male 80y
 - - - Female 70y

- - - Male 70y
 - - - Female 60y
 — Female 80y

Table 1: Age, gender, ASA grade and BMI class of primary TKR and UKR patients

			All	Training set	Test set
Total number	Total knee replacement		842,796	758,516	84,280
	Unicompartmental knee replacement		83,746		
Median age (IQR) [n]	Total knee replacement		70 (64-76) [842,644]	70 (64-76) [758,377]	70 (64-76) [84,267]
	Unicompartmental knee replacement		64 (57-70) [83,728]		
Male gender % [n]	Total knee replacement		42.9% [842,795]	42.9% [758,515]	42.8% [84,280]
	Unicompartmental knee replacement		53.0% [83,745]		
ASA grade % [n]	Total knee replacement	P1	11.4% [95,982]	11.4% [86,831]	11.4% [9,601]
		P2	72.7% [612,476]	72.7% [551,223]	72.7% [61,253]
		P3	15.6% [131,449]	15.6% [118,296]	15.6% [13,153]
		P4/5	0.3% [2,889]	0.3% [2,616]	0.3% [273]
	Unicompartmental knee replacement	P1	22.9% [19,138]		
		P2	69.1% [57,871]		
		P3	7.9% [6,628]		
		P4/5	0.1% [109]		
BMI % ^a [n] <i>Available data</i>	Total knee replacement	Normal	15.2% [74,386]	15.2% [67,017]	15.1% [7,369]
		Underweight	0.3% [1,228]	0.3% [1,109]	0.2% [119]
		Overweight	37.2% [182,520]	37.2% [164,302]	37.2% [18,218]
		Obese	47.4% [232,876]	47.4% [209,652]	47.5% [23,224]
		<i>Available^b</i>	58.3% [491,010]	58.3% [442,080]	58.1% [48,930]
	Unicompartmental knee replacement	Normal	17.1% [8,818]		
		Underweight	0.2% [89]		
		Overweight	41.2% [21,260]		
		Obese	41.6% [21,453]		
		<i>Available^b</i>	61.6% [51,620]		

^a Percentages based on the total number in the subgroup for whom BMI available/between 10-

60kg/m²

^b Number of cases and percentage of the total for which BMI available/between 10-60kg/m²

Table 2: Fixation of TKRs by gender and grouped age at the time of the primary procedure

Age (years) at primary	Male				Female			
	n	Fixation			n	Fixation		
		% cemented	% uncemented	% hybrid		% cemented	% uncemented	% hybrid
<55	19,442	91.1%	7.3%	1.5%	26,777	93.1%	5.5%	1.3%
55-64	85,053	92.7%	6.2%	1.1%	104,644	94.0%	4.9%	1.1%
65-74	147,620	93.9%	5.1%	1.0%	184,812	95.0%	4.1%	0.9%
75+	109,359	94.6%	4.4%	1.0%	164,936	95.3%	3.8%	0.9%

Table 3: Actual cumulative revision rates for primary TKRs and UKRs compared to predicted rates if patients had received a primary TKR.

	Actual cumulative % revision (Kaplan-Meier, with 95%CI) compared with <i>estimated cumulative % revision derived from the 'training' set of 758,376* total knee replacements</i> by years since primary				
	1y	3y	5y	7y	10y
Total knee replacement ('test' set; n=84,267*)	0.4 (0.4,0.5) 0.4	1.6 (1.5,1.7) 1.5	2.2 (2.1,2.3) 2.1	2.6 (2.5,2.7) 2.6	3.3 (3.1,3.5) 3.2
Unicondylar knee replacement (n=83,727*)	1.1 (1.0,1.2) 0.4	4.1 (4.0,4.3) 1.9	6.2 (6.0,6.4) 2.7	8.2 (7.9,8.4) 3.4	11.4 (11.1,11.8) 4.4

* Number of cases available with complete information on the predictors

Table 4: Cumulative revision rates for primary TKRs and UKRs in relation to consultant caseload during the previous year (see text).

TKR			UKR			Fold increase in 10-year revision rate using UKR instead of TKR
Number of TKRs in previous year	Number of primary TKRs included	Cumulative % revised at 10 years (Kaplan-Meier, 95%CI)	Number of UKRs in previous year	Number of primary UKRs included	Cumulative % revised at 10 years (Kaplan-Meier, 95%CI)	
0-36	216,494	3.6 (3.5,3.7)	0-8	22,991	14.2 (13.6,14.8)	3.9 fold
37-63	208,143	3.4 (3.3,3.5)	9-19	19,792	12.0 (11.3,12.8)	3.5 fold
64-99	211,080	3.2 (3.1,3.4)	20-41	20,406	9.7 (9.0,10.4)	3.0 fold
100-440	207,079	3.1 (3.0,3.3)	42-239	20,557	7.6 (6.8,8.5)	2.5 fold

Table 5: Actual cumulative revision rates for primary TKRs, revised TKRs and revised UKRs compared to predicted rates if patients had received a primary TKR.

	Actual cumulative % revision/re-revision (Kaplan-Meier, with 95%CI) compared with <i>estimated cumulative % revision using the model derived from the 'training' set of 758,376* total knee replacements</i> by years since operation				
	1y	3y	5y	7y	10y
Total knee replacement (‘test’ set; n=84,267*)	0.4 (0.4,0.5) 0.4	1.6 (1.5,1.7) 1.5	2.2 (2.1,2.3) 2.1	2.6 (2.5,2.7) 2.6	3.3 (3.1,3.5) 3.2
Revised total knee replacements (n=16,782*)	3.8 (3.6,4.2) 0.4	9.8 (9.3,10.3) 1.6	13.0 (12.4,13.6) 2.2	15.2 (14.5,16.0) 2.8	17.5 (16.4,18.7) 3.5
Revised unicondylar replacement (n=5,383*)	2.7 (2.3,3.2) 0.4	8.0 (7.3,8.9) 1.9	10.9 (9.9,11.9) 2.7	12.7 (11.6,13.9) 3.3	15.2 (13.4,17.1) 4.3

* Number of cases available with complete information on the predictors

Appendix Table 1: Sensitivity analysis of actual cumulative revision rates compared to predicted rates if patients had received a primary TKR where age, gender and BMI group at primary operation is known.

	Actual cumulative % revision (Kaplan-Meier, with 95%CI) for implants where BMI is known at primary operation compared with <i>estimated cumulative % revision derived from the 'training' set of 441,991* total knee replacements</i> by years since primary				
	1y	3y	5y	7y	10y
Total knee replacement ('test' set; n=48,922*)	0.4 (0.4-0.5) 0.4	1.6 (1.5-1.8) 1.5	2.3 (2.1-2.4) 2.1	2.7 (2.5-2.9) 2.5	3.3 (3.0-3.7) 3.0
Unicondylar knee replacement (n=51,605*)	1.0 (0.9-1.1) 0.5	3.8 (3.6-4.0) 1.9	5.6 (5.3-5.8) 2.6	7.3 (7.0-7.6) 3.3	10.2 (9.6-10.9) 4.1

Supplementary Information

Development of a prediction model for cumulative revision from the 90% 'training set' of TKRs

Plots of the smoothed, observed hazard rates suggested peak revision risks 1-2 years post-primary, that declined, with a possible subsequent increase in younger patients although there was sparse data in these groups (Supplementary Figure iv). The peaks were higher and slightly later in younger patients, and slightly higher in men. FPM could accommodate the above in developing a predictive model for cumulative revision.

A series of exploratory analysis (not shown), using gender and age, suggested that a FPM model with 5 degrees of freedom (df), i.e. 4 'knots', for the baseline hazard together with time-varying effects of male gender and age (each with df=5) gave the best fit (Supplementary Figure v). Increased ASA grade (modelled as 2 indicator variables) was significantly associated with increased revision risk, over and above gender and age (n=758,376); the effects were time varying and could be modelled with df=1.

Year of primary was added to the model as a categorical 'fixed' effect. The coefficients for the year of primary (not shown) suggested revision rates increased from 2003 to 2008 and then decreased, confirming the univariate analysis pattern (Supplementary Figure iii) persisted amongst the TKRs, even allowing for temporal changes in gender, age and ASA grade ($p < 0.001$ for differences between the years).

Adding BMI significantly improved the model ($p=0.001$) for the 441,991 'training set' cases for which it was available. A time-varying effect was suggested but it was not statistically significant ($p=0.056$) and did not affect the results shown in the paper.

Development of a prediction model for 90-day mortality from the 90% 'training set' of TKRs

The prediction model developed from the TKR training set ($n=745,803$ unilateral TKRs) used $df=4$ for the baseline hazard and 'fixed' predictors of gender, age, ASA and year of primary.