Supplementary Table i. Data sources and model parameters.

Parameter	Data source: THA	Data source: TKA
Preoperative EQ-5D utility (mapping)	Eibich et al[1] PROMs (n = 271,045)	Eibich et al[1] PROMs (n = 290,893)
Postoperative EQ-5D utility six months after arthroplasty	Eibich et al[1] PROMs (n = 208,344)	Eibich et al[1] PROMs (n = 223,836)
Annual change in EQ-5D utility > six months after arthroplasty, in patients with and without revision	Ara and Brazier[2] 2010 (Model 1)	Eibich et al[1] KAT (n = 15,312 obs of 1,982 pts)
EQ-5D utility before revision	Eibich et al[1] PROMs (n = 1,391 obs of 1,331 pts)	Eibich et al[1] PROMs (n = 2,227 obs of 2,073 pts)
EQ-5D utility after revision	Eibich et al[1] PROMs (n = 880 obs of 860 pts)	Eibich et al[1] PROMs (n = 1,398 obs of 1,331 pts)
Cost of the initial arthroplasty procedure and hospital stay	Eibich et al[1] HES/PROMs (n = 286,507)	Eibich et al[1] HES/PROMs (n = 308,638)
Readmission costs beyond the initial hospital stay		
Year 1	Eibich et al[1] HES/PROMs (n = 236,514)	Eibich et al[1] HES/PROMs (n = 255,194)
> 1 yr after arthroplasty	Eibich et al[1] HES/PROMs (n = 476,514 obs of 173,445 pts)	Eibich et al[1] HES/PROMs (n = 514,047 obs of 182,892 pts)
In the year of revision	Eibich et al[1] HES/PROMs (n = 1,669)	Eibich et al[1] HES/PROMs (n = 2,258)
> 1 yr after revision	Eibich et al[1] HES/PROMs (n = 2,406 obs of 1,177 pts)	Eibich et al[1] HES/PROMs (n = 3,153 obs of 1,583 pts)
Community and outpatient costs beyond the initial hospital stay		
Year 1	Eibich et al[1] KAT (n = 1,841)	Eibich et al[1] COASt (n = 548)
> 1 yr after arthroplasty	Eibich et al[1] KAT (n = 13,271 obs of 1,897 pts)	Pinedo Villanueva[3] 2013
In the year of revision	Eibich et al[1] KAT (n = 88)	Pinedo Villanueva[3] 2013
> 1 yr after revision	Eibich et al[1] KAT (n = 329 obs of 75 pts)	Pinedo Villanueva[3] 2013
Cost of revision arthroplasty procedure and hospital stay	Eibich et al[1] HES/PROMs (n = 2,359)	Eibich et al[1] HES/PROMs (n = 3,416)
Community, outpatient, and inpatient costs in the 12 months before arthroplasty: used to a proxy for costs without arthroplasty	Eibich et al[1] COASt (n = 441)	Eibich et al[1] COASt (n = 278)
Annual change in OHS/OKS without arthroplasty	Assumed no change in OHS/OKS and only age-related decline in EQ-5D utility[2]	Assumed no change in OHS/OKS and only age-related decline in EQ-5D utility[2]
Annual change in EQ-5D utility without arthroplasty	Ara and Brazier 2010[2] (Model 1)	Ara and Brazier 2010[2] (Model 1)
Probability of revision surgery	Pennington et al 2015[4] (assumed that the probability of revision/mortality is unrelated to OHS)	Pennington et al 2016[5] (assumed that the probability of revision/mortality is unrelated to OKS)
Probability of rerevision	Pennington et al 2015[4] (assumed that the probability of revision/mortality is unrelated to OHS)	Pennington et al 2016[5] (assumed that the probability of revision/mortality is unrelated to OKS)
Operative mortality: primary arthroplasty	Pennington et al 2015[4] (assumed that the probability of revision/mortality is unrelated to OHS)	Pennington et al 2016[5] (assumed that the probability of revision/mortality is unrelated to OKS)
Operative mortality: revision arthroplasty	Pennington et al 2015[4] (assumed that the probability of revision/mortality is unrelated to OHS)	Pennington et al 2016[5] (assumed that the probability of revision/mortality is unrelated to OKS)
Healthy patient effect	Pennington et al 2015[4] (assumed that the probability of revision/mortality is unrelated to OHS)	Pennington et al 2016[5] (assumed that the probability of revision/mortality is unrelated to OKS)
All-cause mortality	Office for National Statistics[6]	Office for National Statistics[6]

EQ-5D, EuroQol five-dimension; HES, Hospital Episode Statistics; KAT, Knee Arthroplasty Trial; obs, observations; OHS, Oxford Hip Score; OKS, Oxford Knee Score; PROMs; Patient-Reported Outcome Measures; pts, patients; THA, total hip arthroplasty; TKA, total knee arthroplasty.

Methods for literature reviews

Literature review on previous economic evaluations, costing studies, and decision analytical models. Search strategy:

- Reviewed all papers identified in any of the following systematic reviews:
  - Daigle et al[7] 2012
  - Pinedo Villanueva[3] 2013
  - Nwachukwu et al[8] 2015
- Updated the PubMed search conducted by Daigle et al[7] 2012 on 11th August 2015, looking only at papers published since January 2012: gave 69 hits published after 31 January 2012 using the search string:
  - ((((hip[Title] OR knee[Title] OR joint[Title]) AND (replacement[Title] OR arthroplasty[Title])) AND ((((Cost-utility[Title]) OR Cost-effective*[Title]) OR ("Arthroplasty, Replacement/economics"[Mesh] AND "Cost-Benefit Analysis"[Mesh] AND "Quality-Adjusted Life Years"[Mesh])) OR ("Cost-Benefit Analysis"[Mesh] AND ("Arthroplasty, Replacement/economics"[Mesh] OR "Joint Prosthesis/economics"[Mesh]))))) NOT (prophylaxis[Title] OR blood*[Title] OR rehab*[Title] OR thromboprophylaxis[Title] OR rivaroxaban[Title] OR transfusion[Title] OR autotransfusion*[Title] OR warfarin[Title] OR infect*[Title] OR hormone*[Title] OR discharge[Title])
- CRD searched 11 August 2015: http://www.crd.york.ac.uk/CRDWeb/ResultsPage.asp – searched NHSEED only and only looked at the hits that had publication dates 2012 onwards and had knee arthroplast*OR knee replacement OR hip arthroplast*OR hip replacement in the title. Search strings:
  - ((Knee arthroplast*):TI OR (Knee replacement):TI) and ((Economic evaluation:ZDT and Bibliographic:ZPS) OR (Economic evaluation:ZDT and Abstract:ZPS)) IN NHSEED: 94 hits, of which 33 were 2012 onwards
  - ((Hip arthroplast*):TI OR (Hip replacement):TI) and ((Economic evaluation:ZDT and Bibliographic:ZPS) OR (Economic evaluation:ZDT and Abstract:ZPS)) IN NHSEED : 84 hits, of which 14 were 2012 onwards
- Cost-Effectiveness Analysis (CEA) Registry https://research.tufts-nemc.org/cear4/SearchingtheCEARegistry/SearchtheCEARegistry.aspx (knee OR hip OR joint) AND (arthroplast* OR replacement) – searched 11 August 2015 and only looked at the hits that were 2012 publication date or later.
  - knee replacement: 27 results of which 12 were 2012 or later.
  - knee arthroplasty: 23 results of which 8 were 2012 or later.
  - hip replacement: 32 results of which 12 were 2012 or later.
  - hip arthroplasty: 26 results of which five were 2012 or later.
- Reviewed the complete publications list on the National Joint Registry (NJR) website.
- Reviewed the list of technology appraisals, interventional procedure guidelines, and clinical guidelines related to arthritis on the National Institute of Health and Care Excellence (NICE) website and examined the full text of all relevant documents to assess whether they met inclusion criteria.

Inclusion and exclusion criteria:

- Inclusion criteria for review of models:
  - Decision-analytical model assessing the cost-effectiveness of knee or hip arthroplasty, or the type of surgery performed, or the type of prosthesis used, or the timing of surgery.
- Inclusion criteria for review of costing studies and wider economic evaluations:
  - Any full economic evaluation assessing costs and benefits of knee or hip arthroplasty or the type of surgery performed or the type of prosthesis used, or the timing of surgery.
  - Any costing study collecting patient-level data on costs or resource use for patients undergoing knee or hip arthroplasty.
- Exclusion criteria:
  - Studies on interventions aimed at reducing the risks associated with arthroplasty (e.g. studies on anticoagulants, anaesthesia, or autologous transfusion), or those on post-surgical rehabilitation: these were excluded since they were excluded by the Daigle review and are frequently simple decision trees with a short time horizon.
  - Protocols for trials and registries that do not give any results.
  - Studies not published in either English or German.

Results

- Identified 26 decision-analytical models on hip replacement.[3,4,9-31]
- Identified 19 decision-analytical models on knee arthroplasty.[32-50]
- Identified two papers describing decision-analytical models on both knee and hip arthroplasty.[51,52]
- Identified 13 full economic evaluations or costing studies on hip arthroplasty.[53-65]
- Identified 16 full economic evaluations or costing studies or knee arthroplasty.[66-81]
- Identified 12 full economic evaluations or costing studies on both knee and hip arthroplasty.[82-93]
- The review of economic evaluations identified three previous estimates of the rate of change in utility with age;[2,25,70] we used Ara and Brazier's Model 1[2] in our analysis since it is based on patient-level UK data and is not specific to patients with certain comorbid conditions. The variance-covariance matrix for the model was obtained from the authors.
- Other economic evaluations published after the search date (e.g. Kim et al[94] and Chawla et al[95]) were excluded from the review.

Literature review of studies reporting long-term changes in clinical scores for patients without surgery and long-term changes in EuroQol five-dimension questionnaire (EQ-5D) utility, clinical scores, revision rates, and mortality after surgery. The second literature review aimed to inform a key assumption in the model, by identifying studies that reported changes in clinical tool scores over time for patients without surgery: this is the comparator for the analysis and therefore has a strong influence on the results. A total of 22 such studies were identified.[96-117] However, the reported results were ambiguous. Most studies focused only on changes in Western Ontario and McMaster Universities osteoarthritis index (WOMAC) subscores and only reported data over a two- to five-year follow-up period. Only one study reported results for Oxford Hip Score[105] (OHS) and 12-Item Short-Form Health Survey questionnaire (SF-12),[96] respectively. Overall, the results indicated that patients' clinical tool scores might either improve or worsen, with several studies reporting approximately equal probabilities for both.[102,108,111] We therefore assumed that in the absence of arthroplasty the clinical tool scores remain constant over the ten-year time horizon. However, we did allow for reductions in EQ-5D utility with age.

- Conducted PubMed search on 7th August 2015, using the two search strings:
  - For studies reporting long-term changes in clinical scores for patients without arthroplasty:
    (EuroQoL[Title/Abstract] OR "EQ-5D"[Title/Abstract] OR OHS[Title/Abstract] OR OKS[Title/Abstract] OR (Oxford[Title/Abstract] AND score[Title/Abstract]) OR "SF-12"[Title/Abstract] OR WOMAC[Title/Abstract] OR ("Western Ontario"[Title/Abstract] AND McMaster*[Title/Abstract])) AND ("OSTEOARTHRITIS, HIP"[MeSH Major Topic] OR "OSTEOARTHRITIS, KNEE"[MeSH Major Topic] OR (osteoarthritis AND (hip[Title/Abstract] OR hips[Title/Abstract] OR knee[Title/Abstract] OR knees[Title/Abstract]))) AND ("Regression Analysis"[MeSH Terms] OR "Models, Statistical"[MeSH Terms] OR "prognostic model" OR regression OR "proportional hazards" OR (predict* AND model))
  - For studies reporting long-term changes for patients with arthroplasty:
    (((hip[Title/Abstract] OR knee[Title/Abstract] OR joint[Title/Abstract]) AND (replacement[Title/Abstract] OR arthroplasty[Title/Abstract])) OR "Arthroplasty, Replacement, Knee"[MeSH Terms] OR "Arthroplasty, Replacement, Hip"[MeSH Terms]) AND ("Regression Analysis"[MeSH Terms] OR "Models, Statistical"[MeSH Terms] OR "prognostic model" OR regression OR "proportional hazards" OR (predict* AND model)) AND (WOMAC[Title/Abstract] OR "SF-12" OR (Oxford[Title/Abstract] AND score[Title/Abstract]) OR OHS[Title/Abstract] OR OKS[Title/Abstract] OR ("Western Ontario"[Title/Abstract] AND McMaster*[Title/Abstract]))
- 442 studies were screened (title and abstract) with respect to the inclusion and exclusion criteria for both reviews.
- Reviewed the complete list of publications on the websites of the Osteoarthritis Initiative (OAI) and the Multicenter Osteoarthritis Study (MOST).
- Exclusion criteria for both studies:
  - Patients with diagnoses other than osteoarthritis.
  - Studies not reported in either English or German.
- Exclusion criteria for studies reporting long-term changes after surgery:
  - Less than 500 patients were observed at baseline.
- Inclusion criteria for studies reporting long-term change for patients without surgery:
  - Patients did not have arthroplasty surgery at either baseline or follow-up.
  - Studies reporting changes in WOMAC (total or any subscore), SF-12, OHS, Oxford Knee Score (OKS), or EQ-5D.
- Inclusion criteria for studies reporting long-term change for patients with surgery:
  - Studies reporting changes in EQ-5D, WOMAC (total or any subscore), SF-12, OHS, OKS, revision rates, or mortality rates.
  - Studies following patients for at least two years after surgery.

Results

Studies reporting long-term changes for patients without surgery:

- 22 studies were identified reporting long-term change in clinical scores for patients without surgery.[96-117]
- 21 studies reported changes in WOMAC scores,[97-117] with only one study[116] reporting changes in WOMAC total score. Most studies reported changes in subscores, most commonly WOMAC functioning.
- Two studies reported changes in SF-12 physical scores.[96,99]
- One study reported changes in OHS and EQ-5D alongside changes in WOMAC scores.[105]
- Follow-up duration ranged from 71 days[105] to six years.[96]

Studies reporting long-term changes for patients with surgery:

- 11 studies were identified reporting long-term changes in clinical scores, utility, revision rates, or mortality for patients with surgery.[118-128]
- Six studies reported changes in clinical tool scores.
  - Three studies reported changes in OHS.[121,125,127]
  - Three studies reported changes in OKS.[124,127,128]
  - Two studies reported changes in SF-36 and WOMAC, respectively.[118,119]
- Two studies reported changes in mortality rates.[123,126]
- Four studies reported changes in revision rates.[120,122,125,126]
- Longest follow-up period was ten years.[123-125,128]
- Seven studies reported a predictive model.[118,119,121-125]
- Three of these studies did not report insignificant covariates or the constant.[121,123,124]
- Only one of the remaining papers did not include surgical predictors in their model.[118]

Literature review on models predicting mortality after primary or revision knee/hip arthroplasty. Search strategy:

- Reviewed all studies listed and documents available on NJR website.
- Conducted a very focused MEDLINE search, focusing on studies using NJR data (since it was already known that several recent studies had estimated mortality using NJR data and that this would be the best available UK dataset). We searched MEDLINE through PubMed on 14th July 2015 identified 20 hits, using the search string:

(knee or hip) AND (replacement OR arthroplasty) AND (mortality OR death) AND (UK OR 'United Kingdom' OR England OR Britain OR English OR British) AND ('national joint registry' OR NJR).

Inclusion criteria

- Study were only included if they presented mortality rates stratified by age and sex (plus ideally other baseline characteristics), or present coefficients for regression model(s) predicting mortality after knee and hip arthroplasty.
- We excluded any study with less than 100,000 primary operations, or 10,000 revision procedures, since studies using a similar sample of NJR data had already been identified in earlier reviews.
- We excluded any study not using UK data.

The review identified five studies.[129-133] Three further studies were identified from the review of economic evaluations and models[4,25,126] and a more recent paper in the same series was identified from the authors.[5]

Of these nine studies estimating how mortality varied with age, sex, and/or other characteristics, only one series of studies reported the full set of model coefficients, or considered mortality beyond 90 days after surgery;[4,5,25,126] we therefore used the most recent of these studies in our model.[4,5]

Additional information on model parameters and assumptions

Additional assumptions. The regression models used to estimate model inputs were estimated on datasets in which a minority of patients had bilateral operations, hip resurfacing, unicompartmental knee arthroplasty, or indications other than osteoarthritis. Within the PROMs/HES extract, we were not able to identify the exact type of arthroplasty operation or the indication, so we estimated outcomes on the total population. However, it is likely that the vast majority of patients in the analysis had unilateral total hip/knee arthroplasty for osteoarthritis. We did not restrict the sample by age, although most patients were aged between 50 and 90 years.

Because the model had annual 'cycles', patients could only move between disease states once per year. This means that patients can have a maximum of one revision per year (since they can only enter the 'revision' disease state once per year). In practice, the vast majority of patients will have no revisions in any given year, while a handful may have more than one (particularly in the first year after primary surgery). However, our estimates of the probability of patients undergoing revision in any given year were based on the revision rates calculated by Pennington et al,[4,5] which take account of all revisions that occurred in the NJR, even if patients had more than one revision in the same year. The model therefore includes the costs, surgical mortality, and quality of life changes of all revisions, so the simplifying assumption of annual cycle lengths has no impact on the results.

When modelling the quality-adjusted life-year (QALY) profile, we assumed that EQ-5D utility rises linearly in the first three months after primary THA/TKA and remains constant between three and six months, based on a recent publication.[134] We assumed that utility in subsequent years changed linearly during the year.

We assumed that the utility in the > one year after revision state equalled the post-revision utility that would have occurred if the revision had occurred at the patient's current age.

In the models developed by Pennington et al,[4,5] revision rates have a non-linear relationship with several variables that are not explicitly captured as patient characteristics in our model. In the absence of published national data, we assumed, for simplicity, when calculating revision rates that all patients had a BMI of 30 kg/m^2. In the total hip arthroplasty (THA) models, we also assumed that 41.2% of people had uncemented THA and 23.1% had hybrid THA.[135] In the models of total knee arthroplasty (TKA), we also assumed that all TKA surgery was overseen by a consultant, and that the distribution of patients by prosthesis brand,[135] American Society of Anesthesiologists (ASA) grade,[136] and use of patella resurfacing and antibiotic cement[137] reflected the total population of people in the NJR database.

Cost of unrelated consultations more than one year after THA. For THA, the cost of ambulatory consultations more than one year after hospital discharge was based on an analysis of general practice data done as part of the Clinical Outcomes in Arthroplasty Study (COASt) study[138] since no individual patient data were available. The analyses conducted for COASt included the cost of medication; we therefore took the mean cost of different types of ambulatory consultations from Pinedo Villanueva[3] 2013 (Appendices 40, 41, 46, and 49). These tables provide the absolute difference in the cost of different community/outpatient consultations between men and women of different ages who have had arthroplasty and have either good or poor outcomes, relative to matched controls without arthritis. When applying these we used the published model mapping from total OHS to EQ-5D[139] in reverse, to identify a cut-off on the EQ-5D scale that indicates good or poor outcomes. The mapping model suggested that an OHS of 33 would equal a utility of 0.6624. Using this method, we therefore counted any hypothetical individuals having EQ-5D < 0.6624 (i.e. OHS < 33) as having poor outcomes. In line with the assumption made in the original thesis,[3] patients are generally assigned the community cost for good outcomes if their EQ-5D utility at the start of that particular year was ≥ 0.6624. However, for community costs in the year of revision surgery, patients were assigned costs for good (or poor) outcomes based on their utility after the revision (again, in line with the assumption made in the original thesis). In probabilistic sensitivity analysis (PSA), the costs of each type of consultation were varied independently for each patient subgroup, with no allowance for correlations between different types of consultation. The parameters used in the mapping algorithm (and therefore the cut-off value) were also varied in PSA. Although this constitutes an arbitrary cut-off between good and poor outcomes, this distinction only affects community costs and is the only way to make use of this secondary data, which comprises the best available.

Community, outpatient, and inpatient costs without arthroplasty. We assumed that the costs incurred without arthroplasty (e.g. general practitioner (GP) visits, hospital admissions, physiotherapy etc.) remain constant over the time horizon of the model (i.e. in the absence of arthroplasty surgery, patients will incur the same costs in every year), other than age-related trends. This is in line with the assumption that OHS/OKS will remain constant without arthroplasty. However, we used the cross-sectional COASt data to assess how costs vary with age and applied these coefficients to each patient's age in each year of the model. We estimated the costs without arthroplasty using data on the costs incurred in the year before arthroplasty surgery from the COASt study, which include consultations with a GP, nurse, hospital doctor, physiotherapy, visits to accident and emergency, and admissions to a hospital.

Probabilistic sensitivity analysis (PSA). We estimated the amount of uncertainty around our results using PSA, following best practice guidelines for model-based economic evaluations.[140] In PSA, all model parameters that were not known with certainty were varied simultaneously by randomly drawing values from their distributions. We calculated the costs and QALYs for each hypothetical individual with each of 2,000 sets of model input parameters. We used the PSA results to calculate the probability that arthroplasty is cost-effective for different patient groups at different ceiling ratios representing society's willingness to pay to gain one QALY. We also used PSA results to calculate 95% credible intervals (CrIs) around the threshold OHS/OKS (see below): 95% CrI are analogous to 95% confidence intervals and show the range of values in which we can be 95% certain that the true threshold lies.

In PSA, we allowed for correlations between coefficients estimated in the same regression model, by assuming a multivariate normal distribution.[141] Variance-covariance matrices for published models were obtained from the authors;[2,4,5,139,142] those for the models estimated on patient-level data were estimated in Stata (StataCorp, College Station, Texas, USA) and are available on request. However, for simplicity we did not allow for correlations between the coefficients from different regression models, or between the coefficients for the first and second parts of two-part models.

Differences in the cost of ambulatory consultations after THA[3] were assumed to follow independent normal distributions, while the costs of hip revision surgery[3] in different patient subgroups were assumed to follow independent gamma distributions.

We constrained all utilities to be between -0.594 and 1 in PSA. Costs were also constrained to be ≥ 0 and values that would otherwise be < 0 were set to 0, with the exception of the community costs taken from Pinedo Villanueva[3] 2013. The community costs taken from Pinedo Villanueva[3] 2013 represent differences between resource use for patients with osteoarthritis and those without osteoarthritis; these costs were therefore permitted to be negative in line with the original study.

Base case results represent point estimates, keeping all parameter at their mean values. We used PSA results to calculate 95% CrIs around the threshold OHS/OKS. These intervals were calculated by first examining the results of each individual PSA replicate to identify the threshold OHS/OKS for that PSA draw (within each age group, after taking a weighted average of costs and QALYs across genders). The 95% CrI limits for the threshold were assumed to equal the 2.5th percentile and the 97.5th percentile across the sets of PSA results.

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