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Cost-effectiveness of total shoulder arthroplasty compared to hemiarthroplasty

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Cost-effectiveness of total shoulder arthroplasty compared to hemiarthroplasty

A study using data from the National Joint Registry

Abstract

Objectives

The aim of this study was to compare the cost-effectiveness of total shoulder arthroplasty (TSA) and hemiarthroplasty (HA) and explore variation by age and gender.

Design

Cost-effectiveness analysis using a lifetime cohort Markov model.

Setting

National population registry data.

Participants

Model parameters were informed by propensity score matched comparisons of TSA and HA in patients with osteoarthritis and an intact rotator cuff using data from the National Joint Registry.

Interventions

Total shoulder arthroplasty and hemiarthroplasty

Primary outcome measures

Quality adjusted life years (QALYs) and healthcare costs for age and gender subgroups. A probabilistic sensitivity analysis was performed.

Results

In all subgroups TSA was more cost effective, with probability of being cost-effective about 70% for TSA versus 30% for HA at any willingness-to-pay threshold above of £1,100 per QALY. TSA was dominant in young patients (≤ 60 years) with a mean cost saving of £463 in men and £658 in women, and a mean QALY gain of 2 in both men and women. In patients aged 61-75 years there was a mean cost saving following HA of £395 in men and £181 in women, while QALYs remained superior following TSA with a 1.3 gain in men and 1.4 women. In the older cohort (> 75 years) the cost difference was highest and the QALY difference lowest; there was a cost saving following HA of £905 in men and £966 in women. The mean QALY gain remained larger after TSA: 0.7 in men and 0.9 in women.

Conclusion

TSA was more cost effective than HA in patients with osteoarthritis. QALYs were superior following TSA in all patient groups. Cost differences varied by age and TSA was dominant in young patients.

Strengths and limitations

- Data from the National Joint Registry was used to inform estimates of health utility and cost in matched groups of total shoulder arthroplasties and hemiarthroplasties.
- The analysis was separated by age (≤ 60 years, 61-75 years, >75 years) and gender.
- Modelling assumptions were necessary to estimate parameters beyond the 9 years of available follow-up.
- There remains a risk of confounding of the relationship between TSA and HA despite matching on propensity scores.

Introduction

Shoulder arthroplasties are increasingly used in the management of glenohumeral osteoarthritis (OA) and the annual costs are substantial (1,2). Shoulder arthroplasties can be classified into two groups; anatomical and reverse prostheses. Total shoulder arthroplasty (TSA) and hemiarthroplasty (HA) are anatomical prostheses which are used in patients with an intact rotator cuff. Recent population registry studies showed TSA has a lower rate of revision and re-operation and results in superior Patient Reported Outcome Measures (PROMs) compared to HA (3,4). TSA implants are more expensive and are associated with a longer duration of surgery, therefore the initial cost of a TSA is higher. Furthermore, the risk of revision arthroplasty has been shown to differ by patient age and gender which may result in cost-effectiveness varying in different groups (5).

The management of glenohumeral osteoarthritis in young patients is an area of particular uncertainty. This group has the highest rate of revision and reoperation across the patient's lifetime and the National Institute of Health and Care Excellence (NICE) recommended an economic analysis of TSA vs HA in patients 60 years and under (6). Economic analyses from North America compared TSA with HA and showed TSA to be more costs effective to varying degrees (7–9). The parameters were calculated from observational studies and small randomised trials. The data on which to base the utility assumptions were limited and additional costs of reoperations were not included.

The National Joint Registry (NJR) includes a large population of anatomical shoulder replacements, data entry commenced in 2012 (10). Costs paid for components are collected from hospitals across contributing regions of the United Kingdom to provide a more granular estimate of prosthesis costs. These data provide the opportunity to compare anatomical shoulder arthroplasties within age and gender subgroups. The aim of this study was to determine whether TSA or HA was more cost-effective in the management of glenohumeral osteoarthritis in patients with an intact rotator cuff and explore variation by age and gender.

Method

The Consolidated Health Economic Evaluation Reporting Standards 2022 (CHEERS 2022) reporting guideline was used to inform this report (see appendix) (11).

Population characteristics

The study population for estimation of the revision and re-operation parameters included 14,514 anatomical shoulder arthroplasties from a prior study using NJR data linked to Hospital Episode Statistics (HES) (4). Arthroplasties performed for an indication other than OA or in patients without an intact rotator cuff were excluded. The mean age of the population was 70.1 (SD 9.6), 31.7% male 68.3% female. The majority had an ASA of II or III (ASA I - 9.0%, II - 67.5%, III - 23.0%, IV - 0.4%). 15.2% were in the most deprived socioeconomic quartile, compared to 29.4% in the least deprived quartile as defined in HES (12). The full population characteristics by implant are shown in the appendix.

Model structure and perspective

Cost-effectiveness analysis was undertaken from the perspective of the National Health Service with a maximum time horizon of 60 years. The time horizon varied according to the gender and age-specific mortality rate of UK life tables. The age for the cohort entering the model varied from 40 to 90 years. A Markov model with time-dependency was used, the structure of the model is shown in figure 1. The model simulated a 1,000-patient cohort separately for each age and gender. Patients transitioned through a 6-state model according to specified transition probabilities representing time-dependent risks for annual cycles. The model structure separated subgroup heterogeneity from parametric uncertainty using subgroups defined by age group and gender as previously described (13,14).

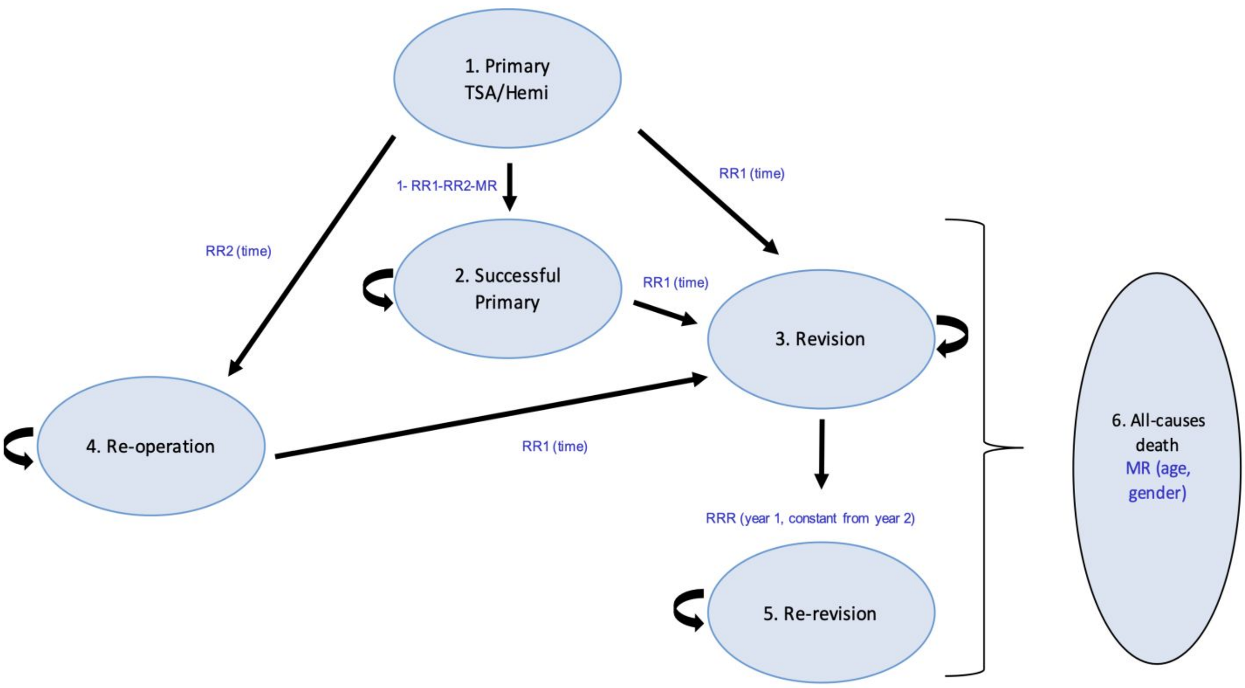

Figure 1. Model structure. RR1 - revision rate, RR2 - re-operation rate, MR - mortality rate, RRR - re-revision rate, MR - mortality rate.

Patients started with a primary TSA or HA and after a 1 year cycle, moved to one of four different heath states (2) to (5): state (2) remain in the 'successful primary'; state (3) 'revision' of their primary arthroplasty; state (4) 'reoperation'; or reached the final state (6). In the next year cycle, a new health state (5) 're-revision' was added to capture patients requiring a second revision procedure. The rest of the cohort evolved across states (2) to (4), and (6) according to the transition probabilities. Cycles were repeated until all patients had died within the 60-year time horizon.

Outcomes – revision, re-operation, and mortality

The rates of revision and re-operation for HA and TSA were estimated using patient-level data from the NJR. The rates were calculated separately for each of three age groups (i) 60 years or younger, (ii) 61-75 years, and (iii) over 75 years. HA and TSA were matched within each age group to minimise baseline differences in population characteristics using 11 covariates reported previously and included in the appendix (4). The standard mean difference (SMD) were less than 0.1 for each of the 11 co-variates. Characteristics of the subgroup populations and details of the matching process are available in the appendix.

Parametric survival models were specified separately to model the implant duration as time-to-event from primary surgery to revision and reoperation for each implant and subgroup, using the Weibull distribution which allows for increasing or decreasing hazards over time, and it has shown good adjustment to estimate time-to-event clinical outcomes for orthopaedic implants (15). The transition probabilities for each cycle, t*p(cycle t),* were calculated using the cumulative hazards, *H(t),* according to the methods described below:

$$tp(cycle\ t) = 1 - exp\{H(t-1) - H(t)\}$$

The cumulative hazard for the Weibull distribution is $H(t) = \lambda t^{\kappa}$, and the parameters λ (scale) and κ (shape) were estimated for each subgroup. A Weibull regression was used to estimate the hazards so that the distribution of time-to-event, T, was a function of gender, age, and the whether the prothesis was HA. The log cumulative hazard function of a Weibull distribution was modelled as follows:

$$lnH(t) = \ lnH0(t) + \beta_0 + \beta_1 age + \beta_1 male + \beta_3 hemiarthroplasty$$

$lnH(t)$ represents the baseline log cumulative hazard at time point t, with $lnH0(t) = \lambda + \kappa \ln(t)$. The effect of HA was measured as a multiplicative effect (additive in the log scale) with the estimated coefficient β_3, so that the rate of revision or re-operation was larger for HA than for TSA if $\beta_3 > 0$, with the multiplicative effect measured by the hazard ratio which is $\exp(\beta_3)$.

The rate of re-revision following a successful revision was taken from a meta-analysis (16). The transition to death was considered as all-cause mortality, measured from the most recent 2018-20 UK life tables, as no deaths were observed during surgery (4). The life tables present the mortality rate for each age separately for men and women. The mortality rate from age 40 to 100 were used as the transition probabilities to death for each age within each one of the three age groups.

Outcomes – health related quality of life

Oxford shoulder scores (OSSs) from a previous population-level comparative study were used to estimate health-related quality of life (HRQoL) (17). The results were skewed towards the highest score and the median score was used for the purpose of the quality of life estimations (3). The OSSs were mapped to the EQ-5D-5L (17). There was minimal change in the OSS from 6 months to 5 years (3). The model addressed the postoperative recovery period in year 1 by halving the improvement in the EQ-5D-5L value from baseline for the first 6 months followed by the full EQ-5D-5L for the second 6 months. There was no further change in HRQoL after 1 year.

Reports of shoulder scores in revision arthroplasty are very limited (16). Revision utilities were estimated as 15% less than the combined TSA and HA EQ-5D values. This estimate was made from a combination of data in shoulder and knee arthroplasty (14,16) The same trajectory of improvement in HRQoL in the first year was applied to the revised state. HRQoL following re-revision was assumed to fall by the same proportion as it did from primary to revision arthroplasty. Full details of HRQoL estimations are included in the appendix.

Cost estimates

The primary source of information for cost estimation were hospital reimbursement values for shoulder procedures from the 2022/2023 National Tariff Payment System using Healthcare Recourse Group (HRG) codes (18). The codes do not differentiate between the two types of anatomical shoulder arthroplasty. Two key elements of the total cost of each procedure were used to estimate the difference between primary HA and TSA: length of the procedure and component costs. Costs are described in the British Pound (GBP). Data from the NJR EMBED price benchmarking service was used to calculate the mean price of TSA and HA components (19). The HRG code HN52 "Very Major

Shoulder Procedures for Non-Trauma" was used as the baseline cost for HA and TSA (18). Theatre time costs were calculated using estimated durations of surgery combined with theatre time cost estimations, the full calculation is available in the appendix (20,21). The total difference in cost was halved and added to the HRG value to estimate the TSA cost and subtracted from the HRG value to estimate HA cost. This meant the mean cost of HA and TSA was equal to the NH52 code value. See the appendix for further information and the individual values.

The cost of a revision and re-revision arthroplasty was estimated from relevant HRG codes and assumed to be equal between the groups. The model did not include community costs which are minimal compared with the overall cost (14). A discount rate of 3.5% was applied for costs and health outcomes as recommended by NICE (22).

Parameter distributions for the probabilistic sensitivity analysis

Estimation by subgroups separated demographic heterogeneity from parameter uncertainty, the latter was modelled as a probabilistic sensitivity analysis (PSA). The probability distributions used for the input parameters were informed by the sample means and variability. For the parameters of the Weibull survival models the distributions were multivariate log-normal. To estimate random values from the survival models the raw coefficients (β_0, β_1, β_2, β_3, κ) were assumed to follow a multivariate normal distribution with a correlation structure given by the coefficients from the correlation matrix. Cholesky decomposition of the covariance matrix was performed to simulate the correlated random variates (13). The parameters of the re-revision rate were assumed to follow a beta distribution. The beta distribution was also used to introduce uncertainty in health utilities on the assumption that no value was less than 0, as observed in the data. The gamma distribution was used to model cost uncertainty due to its favourable properties in this context as a positive and skewed distribution (13).

Final analyses

The model outcomes were estimated separately by gender and age for each of the three age groups: (i) 60 years or younger, (ii) 61-75 years, and (iii) over 75 years. Mean Quality Adjusted Life Year (QALYs) and costs were calculated for TSA and HA and were presented as incremental cost-effectiveness ratios (ICERs). Monte Carlo simulations were used to address parametric uncertainty by generating 1,000 random draws of the assumed statistical distributions for the input parameters. For each one of the three patient subgroups, for a given age and gender, the differential mean costs and QALYs between TSA and HA were calculated. The initial assessment compared these means and established whether one implant dominates the other (if it is less costly and generate more QALYs) or whether it is cost-effective, with incremental costs and incremental QALYs, if the incremental cost per QALY, known as incremental cost-effectiveness ratio (ICER), is below the NICE cost-effectiveness threshold established between £20,000-£30,000 per QALY. The probability of either TSA or HA being cost effective was calculated for a range of cost-effectiveness thresholds and the cost-effectiveness acceptability curves (CEAC) were drawn for each patient subgroup. The analyses used to generate the parameter estimates were performed using StataSE v 16 (StataCorp LLC, College Station, TX). The cost effectiveness model was constructed in EXCEL Version 16.80 (Microsoft Corporation, Redmond, Washington). The Markov models were simulated in Excel.

Results

Input parameter values

HA increased the rate of revision and re-operation for the three age groups, more strongly for revision in younger patients than for over 75-year-olds. The estimated mean EQ-5D-5L utility was higher following primary TSA compared to primary HA (Appendix Table 1). The mean cost of a primary TSA was £6576 compared to £5456 following HA (Appendix Table 14). Other input parameters were taken from the National Tariff Payment System and the literature. The full tables of input parameters are included in the appendix.

Main findings

TSA dominated HA in the young cohort, with TSA resulting in mean cost savings of £463 and a 2.0 QALY gain in men, and a saving of £658 and 2.0 QALY gain in women entering the model at age 50 and representing patients aged 60 years and younger. The cost savings reversed for the older cohort entering at age 80, representing patients over 75, with HA around £966 less costly than TSA in women, and £905 less costly in men but with 0.9 QALYs less than TSA in women and 0.7 in men. For the middle cohort entering the model at age 67 and representing ages 61-75, there was a cost saving following HA in men and women. TSA resulted in a QALY gain of 1.3 for men and 1.4 for women. The probability of TSA being more cost-effective than HA was constant at around 70% for all willingness-to-pay thresholds considered in decision-making in the UK (£20,000 to £30,000 per QALY). The cost-effectiveness planes for each age group in females and males are shown in figures 2 and 3. The results of the cost-effectiveness analyses are presented for each age cohort. Gender subgroup heterogeneity was indistinguishable from parametric uncertainty in the cost-effectiveness (CE) plane therefore the cost-effectiveness acceptability curves (CEAC) are presented for women only (figure 4). The CEAC for men is available in the supplementary material.

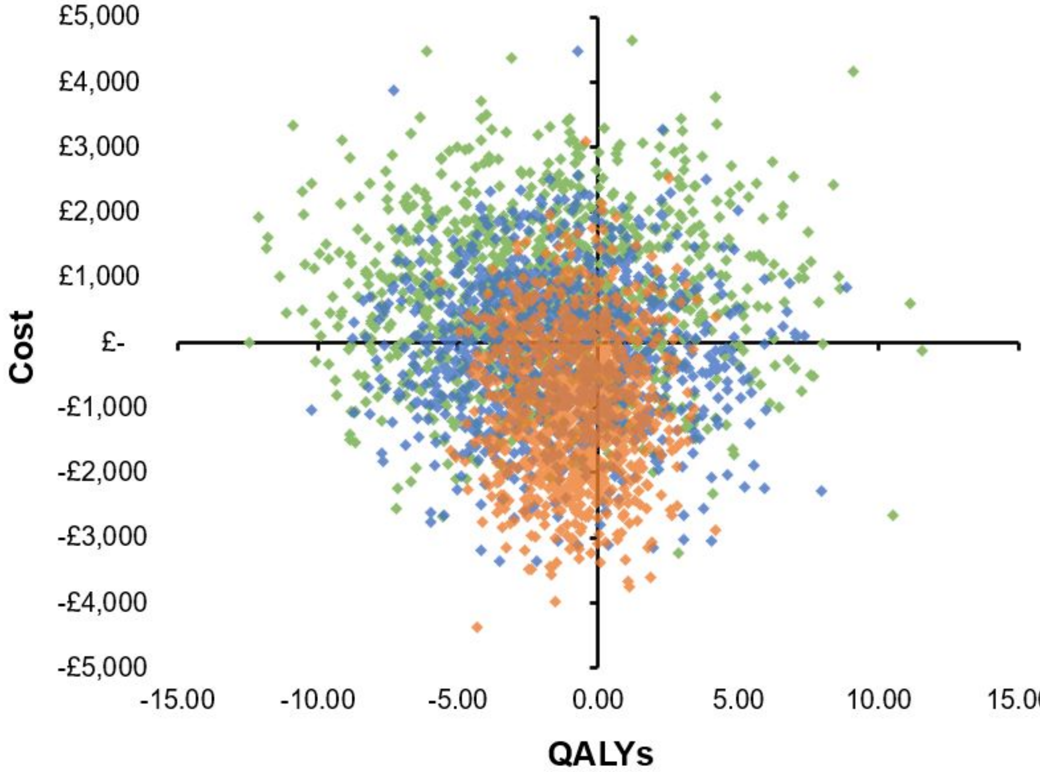

Figure 2. Cost-effectiveness plane: Female 50 – Green, female 67 – Blue, female 80 – Orange. QALYS – Quality Adjusted Life Years.

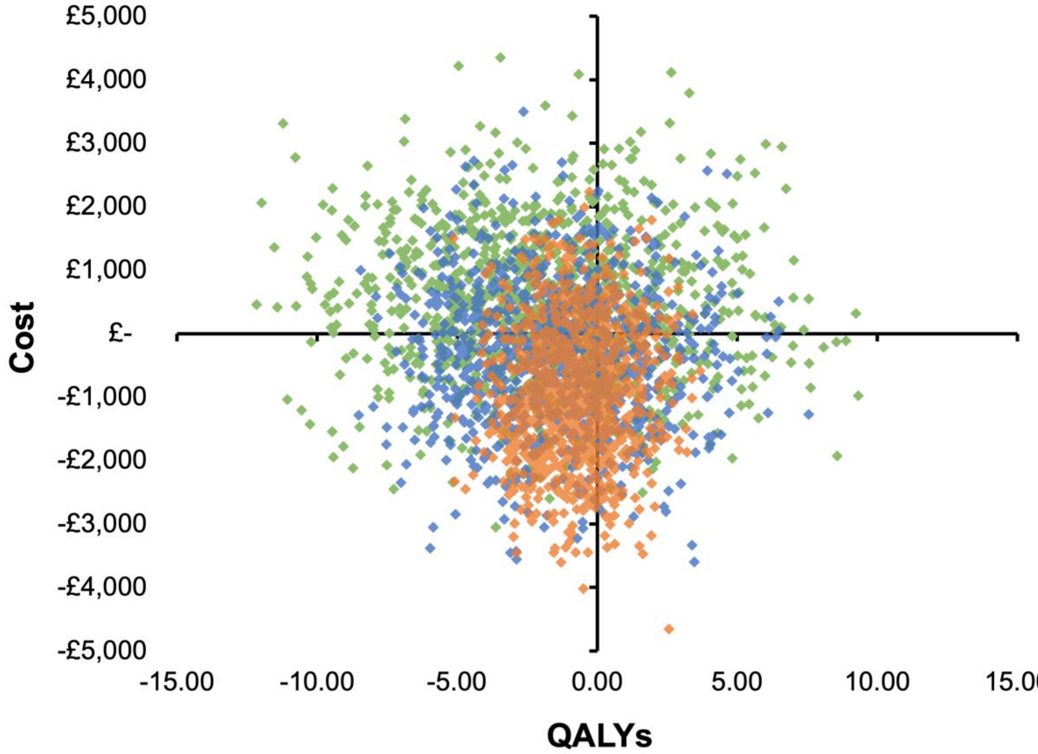

Figure 3. Cost-effectiveness plane: Male 50 – Green, male 67 – Blue, male 80 – Orange. QALYS – Quality Adjusted Life Years.

	TSA Mean		**HA** Mean		**Difference (HA – TSA)**		**ICER**	
	Cost (£) (95% CI)	QALYs (95% CI)	Cost (£) (95% CI)	QALYs (95% CI)	Costs (£) (95% CI)	QALYs (95% CI)	Cost per QALY (£)	(Prob. TSA cost effective)
Female ≤ 60	9,223 (9,160, 9,287)	13.63 (13.5,13.8)	9,882 (9,817, 9,946)	11.64 (11.5,11.8)	658 (581,735)	-1.99 (-2.2,-1.8)	-331	69%
Male ≤ 60	8,610 (8,553, 8,666)	13.01 (12.9, 13.2)	9,073 (9,012, 9,133)	11.00 (10.8,11.2)	463 (387,538)	-2.01 (-2.3,-1.8)	-230	71%
Female 61-75	7,548 (7,493, 7,602)	9.30 (9.2,9.4)	7,367 (7,316, 7,418)	7.85 (7.7,8.0)	-181 (-253,-109)	-1.44 (-1.6,-1.26)	126	69%
Male 61-75	7,291 (7,238, 7,344)	8.51 (8.4,8.6)	6,895 (6,846, 6,945)	7.25 (7.1,7.4)	-395 (-466,-325)	-1.26 (-1.4,-1.1)	314	68%
Female > 75	6,861 (6,808, 6,914)	5.26 (5.2,5.3)	5,895 (5,848, 5,943)	4.32 (4.2,4.4)	-966 (-1,038, - 893)	-0.94 (-1.1,-0.8)	1,024	70%
Male > 75	6,807 (6,754, 6,859)	4.60 (4.5,4.7)	5,902 (5,854, 5,950)	3.87 (3.8,3.9)	-905 (-976,- 833)	-0.73 (-0.8,-0.6)	1,236	68%

Notes:

The 95% CI is estimated using the standard error of the mean is SEM=SD/$\sqrt{1000}$, where SD is the sample standard deviation of the 1,000 random draws in the PSA.

Table 1. Costs, quality adjusted life years (QALYs), and cost-effectiveness for age and gender subgroups.

Young cohort ≤ 60 years

The slightly smaller costs and QALYs for men compared to women were consistent with lower hazard ratios for revision and re-operation in men along with a shorter lifespan: men accumulate less costs and QALYs during the predicted time horizon. The mean ICERs for women and men aged 50 were negative in the North-West area of the CE plane, with incremental costs and decremental QALYs, therefore TSA was dominant. The rates of revision and re-operation were estimated separately for each age within the cohort. There was a decrease in costs and QALYs as age increased (figures shown in the appendix). The difference in costs between TSA and HA decreased with age reflecting the progressive shortening of life span. In contrast, the difference in QALYs remained similar by age.

The CEAC shown in figure 5 imply that TSA had a higher probability of being cost-saving that HA, even at the willingness-to-pay threshold of £0 (indicating cost-savings), due to the larger hazards of revisions and reoperations for HA than TSA whose costs offset the difference in initial cost. The QALY gain reinforces the probability of TSA being dominant over TA.

Middle cohort 61 – 75 years

The overall costs for HA were lower than TSA. The cost of TSA was slightly higher following HA in males and females. TSA rendered more QALYs than HA in both males and females, therefore the ICER was positive but on the South-West quadrant of the CE plane. This quadrant is used for disinvestment decisions (withholding the replacement) if the savings are large – at least more than £20,000-£30,000 according to NICE threshold – which was not this case. To show that HA was not cost effective, the net monetary benefit (NMB) was calculated for females, and it was negative, which showed HA was not cost-effective:

$$NMB = Threshold * \Delta QALY - \Delta Cost = £20{,}000 * (-1.44) - (-181) = -28{,}981$$

At the willingness-to-pay threshold of £0, there was cross-over; both HA and TSA had the same probability of being cost saving. The hazards of revision and re-operation were still larger for HA than TSA, however the middle cohort accumulated less years of costs.

Older cohort over 75 years

The older cohort accumulated the fewest years of costs and QALYs. The hazards of revision and re-operation remained larger for HA than TSA but the greatest cost saving following HA was shown in this cohort. For both female and male aged 80, HA was less costly than TSA because the HA prosthesis is cheaper and the incremental costs from more reoperations and revisions were negligible. However, the savings did not justify a disinvestment in TSA or replacing TSA by HA. Differential QALYs favour TSA, and the NMB was negative (NMB=-17,834 = 20,000*(-0.94)-(-966)).

At the willingness-to-pay threshold of £0, HA was more likely to be cost saving. At a threshold of £1100 – £1250 per QALY, there was cross-over in the probability of HA and TSA being cost-effective, and TSA is more cost-effective, with probability up to 68% for men for a threshold over £1250 per QALY.

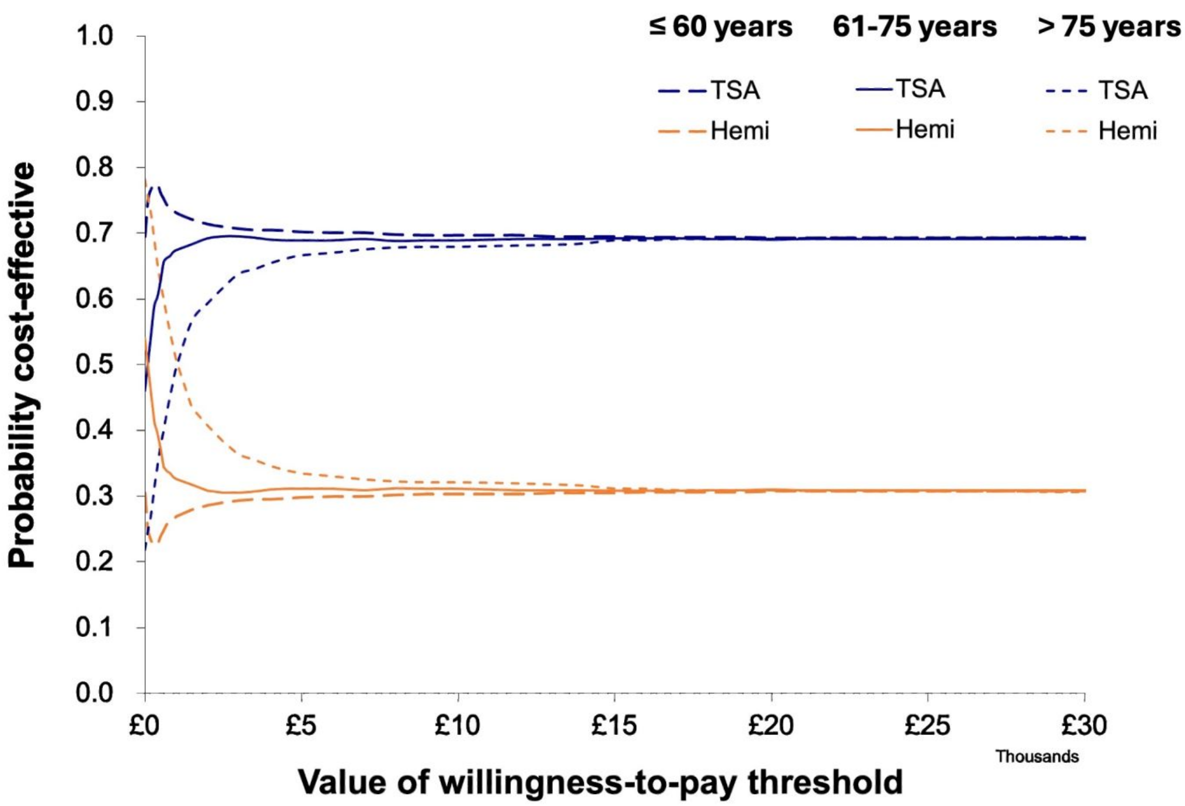

Figure 4. Cost-effectiveness acceptability curve in women.

Discussion

Principal findings

The results showed cost effectiveness was likely to be higher following TSA for all age subgroups at a threshold of £20,000-£30,000 per QALY. QALYs were higher for TSA in all age groups. In the young cohort costs were higher following HA. Despite the lower costs of HA implants and shorter theatre time, this was offset by the additional costs of revision/re-operation. In the older cohort TSA was more expensive than HA because the higher initial costs were not offset by the lower overall rate of revision and reoperation after TSA during patients' shorter lifetime. The sensitivity analyses accounted for the uncertainty in the estimates and within each age group the probability of cost-effectiveness was approximately 0.7 for TSA at current NICE threshold of £20,000-£30,000 per QALY. There is particular interest in the cost-effectiveness of anatomical shoulder replacements in young patients (6). TSA was dominant in patients 60 years and younger at a willingness to pay threshold of £0, primarily due to the large difference in revision rate and longer lifetime of patients in this subgroup, implying TSA is cost saving compared to HA. Postoperative shoulder function may determine whether patients can return to work (23). As the number of shoulder arthroplasties performed each year increases, including in young patients, the loss of productivity due to the additional time required off work should be considered. This further supports the economic arguments for TSA given the superior post-operative shoulder function.

Strengths and limitations

This is the first study to investigate cost-effectiveness in anatomical shoulder replacements using parameter estimates based on National registry data from the U.K., and the first to investigate cost-effectiveness in young patients. Age is an important driver of revision rate, and the analysis was split into 3 age subgroups to better represent subgroup differences in cost-effectiveness across the population. Confounding by indication remained a concern and arthroplasties within each age group

were matched on propensity scores calculated from 11 important variables to minimise the risk of baseline differences between the groups. The study was limited to patients with osteoarthritis and an intact rotator cuff. Revision and re-operation estimates were based on models extrapolated from registry data with a maximum follow-up of 9 years.

Modelling assumptions were necessary. Individuals could not undergo revision or re-operation within the first year following the primary procedure, and revision and re-operation could not occur within the same year. We assumed there was no change in utility after the first 6 months, and the annual utility was averaged accordingly. The OSS may continue to improve beyond 6 months after TSA, and the ceiling affect shown in the OSS at 5 years may result in an underestimate of the improvement. The same trajectory of utility following revision surgery was assumed. The utility estimates required transformation of the OSS to the EQ5D. Despite a mapping algorithm based on high quality data, this introduced additional uncertainty. Revision utilities were estimated by reducing the combined primary utility by 15%. In a prior systematic review shoulder scores were collected following revision arthroplasty but only one small study of 15 patients reported OSSs following TSA and none following HA (16). No mapping studies are available to estimate the EQ5D from other shoulder scores.

The cost estimates centred around hospital reimbursement values to improve the generalisability of the results. The cost of theatre time will vary by unit, a range of values are reported, and there is uncertainty among hospital managers (24). The value selected for this work was taken from pooled data from NHS Scotland (21). A median value of implant costs nationally was used to ensure they were generalisable compared to the alternative of relying on procurement costs of a limited number of implants from a single, or small number of hospitals. A single reimbursement code was used for each of the re-operation and revision procedures representing patients with moderate co-morbidities. The standard deviation of the cost estimates for re-operation and revision were assumed to be 10% of the cost of the procedure. Post-operative mortality was assumed to be equivalent to age and gender specific mortality recorded nationally, no evidence could be found to contradict this assumption. Previous work showed there was no difference between the implants at 1 year (4). The national life tables were considered a more accurate predictor of death than summary estimates generated from a relatively small population for this rare outcome. If the rate of death was higher following surgery than in the general population, this may overestimate the cost-effectiveness of both implants.

Comparison to other studies

Prior work comparing the cost-effectiveness of HA and TSA, is from North America (7–9). The most recent study by Lapner et al showed TSA was more cost-effective (7). The results were more strongly in favour of TSA than in this study, which may be a product of the difference in North American costs compared to U.K. costs, and the revision and utility estimates. The utility assumptions for TSA were based on a paper which has since been retracted, and the utility assumptions for HA were based on patients following proximal humerus fractures which may underestimate the effect of HA (7). The earlier studies used more limited datasets and showed superiority of TSA to varying degrees (8,9). Given the sensitivity of the models to revision rate shown in this study, the quality of the data used to estimate implant survival is particularly important.

The use of HA has declined however it continues to be used, most commonly in younger patients, where there is particular uncertainty about the most appropriate implant (6). This study showed TSA was cost effective in the management of glenohumeral osteoarthritis, and the superiority of TSA was most clear in the younger cohort.

Funding statement

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Ethical approval

The study used pseudo-anonymised data from a national clinical registry. The Health Research Authority guidance confirmed ethical approval was not required.

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Competing interests

PR receives funding for alternative work from Mathys and Orthopaedic Research UK. AR receives funding for alternative work from the NIHR, AO UK&I and DePuy J&J Ltd. AR is a member of the NIHR i4i funding committee.

Data sharing arrangement

Original data can be requested from the National Joint Registry

Patient and public involvement

Patients were involved in the wider body of work comparing total shoulder arthroplasty and hemiarthroplasty.

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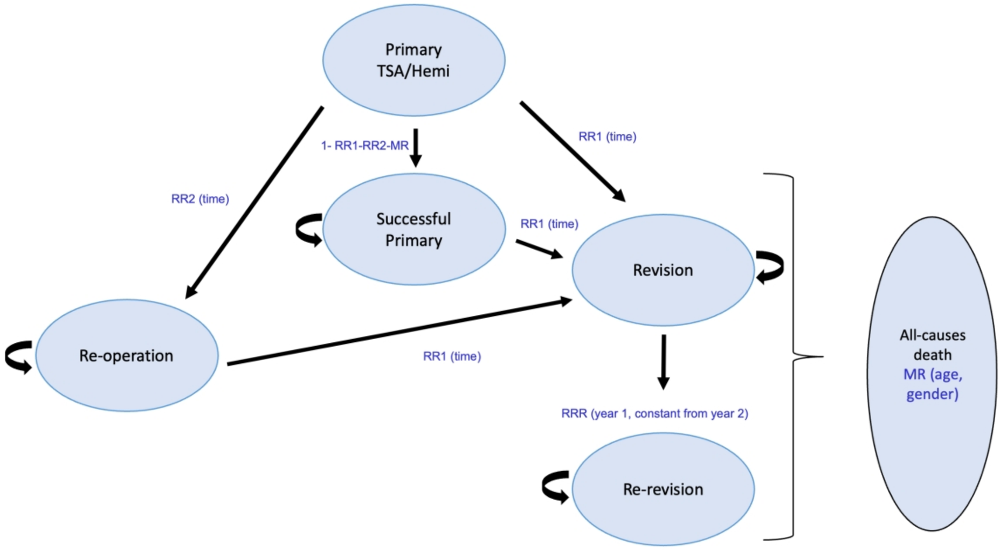

Figure 1. Model structure. RR1 - revision rate, RR2 - re-operation rate, MR - mortality rate, RRR - re-revision rate, MR - mortality rate.

236x130mm (250 x 250 DPI)

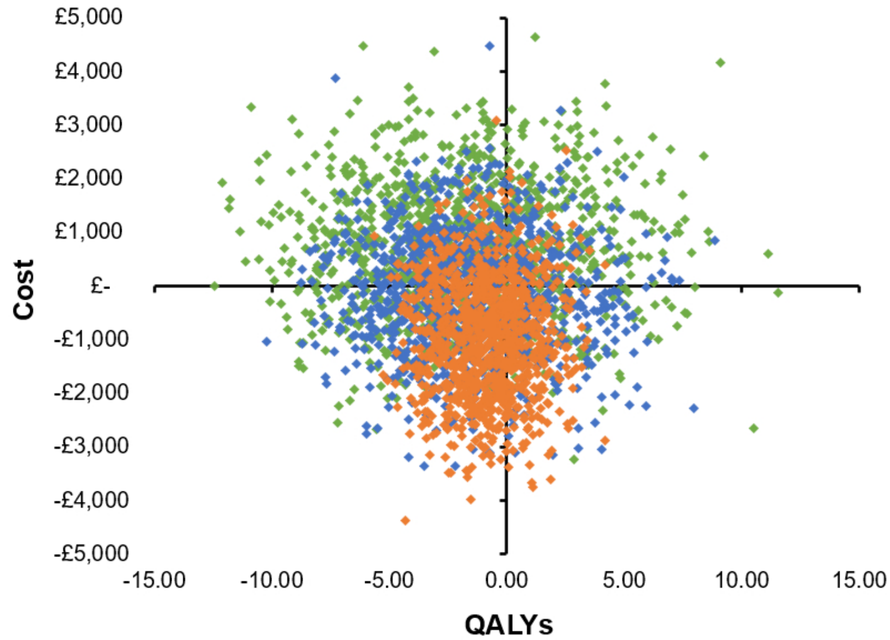

Figure 2. Cost-effectiveness plane: Female 50 – Green, female 67 – Blue, female 80 – Orange. QALYS – Quality Adjusted Life Years.

317x215mm (72 x 72 DPI)

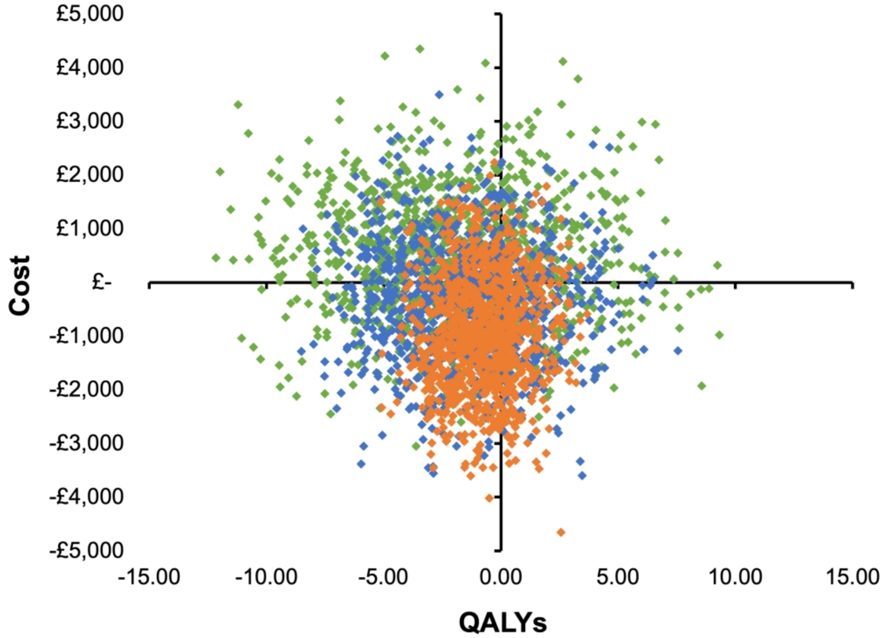

Figure 3. Cost-effectiveness plane: Male 50 – Green, male 67 – Blue, male 80 – Orange. QALYS – Quality Adjusted Life Years.

1096x745mm (72 x 72 DPI)

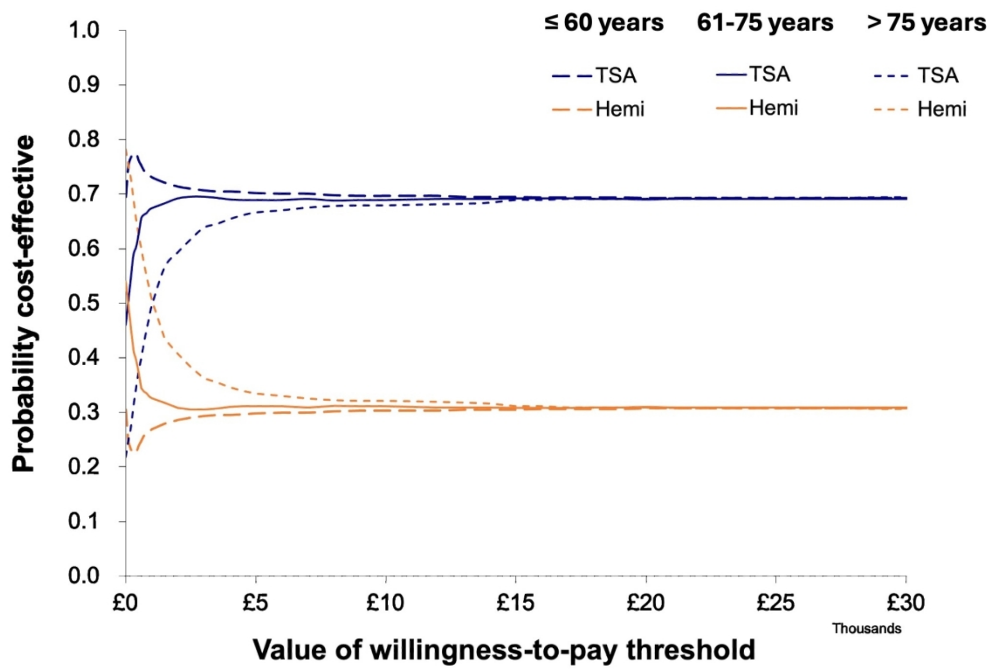

Figure 4. Cost-effectiveness acceptability curve in women.

209x139mm (250 x 250 DPI)

Appendix

Model parameters – health utility

Prosthesis	Procedure	EQ-5D-5L	Standard deviation
TSA	Success Primary	0.76	0.18
	Success Revision	0.61	0.18
	Recovery Primary	0.66	0.18
	Recovery Revision	0.54	0.18
	Re-revision	0.54	0.18
	Pre-operative	0.34	0.18
Hemi	Success Primary	0.64	0.22
	Success Revision	0.61	0.22
	Recovery Primary	0.58	0.22
	Recovery Revision	0.54	0.22
	Re-revision	0.54	0.18
	Pre-operative	0.35	0.18

Table 1. EQ-5D-5L utility scores.

Number of shoulders arthroplasties in each age group

Age group	Pre-matching		Post-matching	
	TSA	**HA**	**TSA**	**HA**
≤ 60 years	1471	746	1177	623
61 – 75 years	6002	2010	3714	1889
> 75 years	3008	1461	2323	1236

Table 2. Number of shoulder arthroplasties in each age group.

Characteristics pre and post matching – subgroup aged 60 years or less

	Pre-matching			Post-matching		
Characteristic	TSA	HA	SMD	TSA	HA	SMD
Age (mean, SD)	54.5 (5.4)	52.0 (7.4)	0.382	53.8 (5.7)	53.6 (5.7)	0.042
Gender (number, %)						
Male	767 (52.1)	481 (64.5)	0.252	681 (57.9)	382 (61.3)	0.071
Female	704 (47.9)	265 (35.5)		496 (42.1)	241 (38.7)	
ASA (number, %)						
I	283 (19.2)	203 (27.2)	0.197	248 (21.1)	144 (23.1)	0.054
II	950 (64.6)	422 (56.6)		724 (61.5)	377 (60.5)	
III	230 (15.6)	118 (15.8)		200 (17.0)	99 (15.9)	
IV	8 (0.5)	3 (0.4)		5 (0.4)	3 (0.5)	
Rotator cuff (number, %)						
Attenuated/normal	1460 (99.3)	730 (97.9)	0.117	1166 (99.1)	617 (99.0)	0.003
Repaired	11 (0.7)	16 (2.1)		11 (0.9)	6 (1.0)	
Operating surgeon (number, %)						
Consultant	1369 (93.1)	704 (94.4)	0.168	1117 (94.9)	593 (95.2)	0.016
SpR/ST3-ST8	46 (3.1)	30 (4.0)		39 (3.3)	20 (3.2)	
Speciality doctor	31 (2.1)	4 (0.5)		8 (0.7)	4 (0.6)	
F1-ST2	0 (0.0)	1 (0.1)		0 (0.0)	0 (0.0)	
Other	25 (1.7)	7 (0.9)		13 (1.1)	6 (1.0)	
Surgical assistant (number, %)						
Consultant	121 (8.2)	59 (7.9)	0.012	95 (8.1)	45 (7.2)	0.032
Other	1350 (91.8)	687 (92.1)		1082 (91.9)	578 (92.8)	
Surgical approach (number, %)						
Deltopectoral	1369 (93.1)	704 (94.4)	0.213	1096 (93.1)	573 (92.0)	0.071
Deltoid detachment	4 (0.3)	1 (0.1)		1 (0.1)	1 (0.2)	
Other	2 (0.1)	0 (0.0)		0 (0.0)	0 (0.0)	
Posterior	3 (0.2)	2 (0.3)		3 (0.3)	2 (0.3)	
Superior (Mackenzie)	69 (4.7)	63 (8.4)		66 (5.6)	40 (6.4)	
Trans-deltoid	24 (1.6)	13 (1.7)		11 (0.9)	7 (1.1)	
Unit type (number, %)						
NHS	1440 (97.9)	735 (98.5)	0.048	1159 (98.5)	613 (98.4)	0.006
Independent	31 (2.1)	11 (1.5)		18 (1.5)	10 (1.6)	
Cases / yr (mean, SD)	9.3 (5.5)	8.2 (4.9)	0.198	8.5 (5.0)	8.4 (5.0)	0.033
Charlson Comorbidity Index(mean, SD)	0.8 (1.3)	0.8 (1.3)	0.006	0.8 (1.3)	0.8 (1.3)	0.025
Deprivation level (number, %)						
Least deprived	314 (21.6)	180 (24.3)	0.080	268 (22.8)	149 (23.9)	0.032
Less deprived	401 (27.6)	185 (25.0)		314 (26.7)	160 (25.7)	
More deprived	391 (26.9)	205 (27.7)		323 (27.4)	172 (27.6)	
Most deprived	349 (24.0)	170 (23.0)		272 (23.1)	142 (22.8)	

Table 3. Characteristics pre- and post-matching, patients age 60 years or less.

Characteristics pre and post matching – subgroup aged 61-75 years

	Pre-matching			Post-matching		
Characteristic	TSA	HA	SMD	TSA	HA	SMD
Age (mean, SD)	69.0 (4.0)	69.0 (4.1)	0.003	69.0 (4.1)	68.9 (4.1)	0.013
Gender (number, %)						
Male	1913 (31.9)	692 (34.4)	0.054	1262 (34.0)	652 (34.5)	0.011
Female	4089 (68.1)	1318 (65.6)		2452 (66.0)	1237 (65.5)	
ASA (number, %)						
I	480 (8.0)	170 (8.5)	0.077	313 (8.4)	157 (8.3)	0.019
II	4252 (70.8)	1369 (68.1)		2526 (68.0)	1290 (68.3)	
III	1259 (21.0)	461 (22.9)		865 (23.3)	435 (23.0)	
IV	11 (0.2)	10 (0.5)		10 (0.3)	7 (0.4)	
Rotator cuff (number, %)						
Attenuated/normal	5945 (99.1)	1961 (97.6)	0.116	3660 (98.5)	1865 (98.7)	0.016
Repaired	57 (1.5)	49 (2.4)		54 (1.5)	24 (1.3)	
Operating surgeon (number, %)						
Consultant	5465 (91.1)	1838 (91.4)	0.077	3404 (91.7)	1735 (91.8)	0.009
SpR/ST3-ST8	120 (2.0)	23 (1.1)		205 (5.5)	101 (5.3)	
Speciality doctor	289 (4.8)	111 (5.5)		60 (1.6)	31 (1.6)	
Other	128 (2.1)	38 (1.9)		45 (1.2)	22 (1.2)	
Surgical assistant (number, %)						
Consultant	540 (9.0)	192 (9.6)	0.019	377 (9.1)	177 (9.4)	0.010
Other	5462 (91.0)	1818 (90.4)		3377 (90.9)	1712 (90.6)	
Surgical approach (number, %)						
Deltopectoral	5569 (92.8)	1771 (88.1)	0.189	3379 (91.0)	1733 (91.7)	0.045
Deltoid detachment	9 (0.1)	3 (0.1)		7 (0.2)	3 (0.2)	
Other	12 (0.2)	4 (0.2)		7 (0.2)	4 (0.2)	
Posterior	10 (0.2)	6 (0.3)		8 (0.2)	5 (0.3)	
Superior (Mackenzie)	283 (4.7)	180 (9.0)		246 (6.6)	108 (5.7)	
Trans-deltoid	119 (2.0)	46 (2.3)		67 (1.8)	36 (1.9)	
Unit type (number, %)						
NHS	5901 (98.3)	1985 (98.8)	0.037	3669 (98.8)	1864 (98.7)	0.010
Independent	101 (1.7)	25 (1.2)		45 (1.2)	25 (1.3)	
Cases / yr (mean, SD)	9.8 (5.6)	8.2 (5.3)	0.304	8.5 (5.1)	8.2 (5.1)	0.060
Charlson Comorbidity Index(mean, SD)	1.1 (1.6)	1.1 (1.5)	0.001	1.1 (1.5)	1.1 (1.5)	0.009
Deprivation level (number, %)						
Least deprived	1655 (28.0)	611 (30.5)	0.073	1114 (30.0)	581 (30.8)	0.022
Less deprived	1945 (32.9)	598 (29.9)		1096 (29.5)	560 (29.6)	
More deprived	1417 (24.0)	483 (24.1)		917 (24.7)	451 (23.9)	
Most deprived	887 (15.0)	311 (15.5)		587 (15.8)	297 (15.7)	

Table 4. Characteristics pre- and post-matching, patients age 61-75 years.

Characteristics pre and post matching – subgroup aged > 75 years

	Pre-matching			Post-matching		
Characteristic	TSA	HA	SMD	TSA	HA	SMD
Age (mean, SD)	80.1 (3.5)	80.9 (3.9)	0.221	80.4 (3.6)	80.4 (3.6)	0.016
Gender (number, %)						
Male	584 (19.4)	236 (16.2)	0.085	410 (17.6)	220 (17.8)	0.004
Female	2424 (80.6)	1225 (83.8)		1913 (82.4)	1016 (82.2)	
ASA (number, %)						
I	120 (4.0)	70 (4.8)	0.092	103 (4.4)	57 (4.6)	0.019
II	2013 (66.9)	914 (62.6)		1492 (64.2)	797 (64.5)	
III	854 (28.4)	466 (31.9)		712 (30.7)	372 (30.1)	
IV	21 (0.7)	11 (0.8)		16 (0.7)	10 (0.8)	
Rotator cuff (number, %)						
Attenuated/normal	2966 (98.6)	1429 (97.8)	0.060	2284 (98.3)	1216 (98.4)	0.005
Repaired	42 (1.4)	32 (2.2)		39 (1.7)	20 (1.6)	
Operating surgeon (number, %)						
Consultant	2666 (88.6)	1308 (89.5)	0.163	2076 (89.4)	1118 (90.5)	0.069
SpR/ST3-ST8	71 (2.4)	11 (0.8)		133 (5.7)	74 (6.0)	
Speciality doctor	154 (5.1)	102 (7.0)		82 (3.5)	33 (2.7)	
Other	117 (3.9)	40 (2.7)		32 (1.4)	11 (0.9)	
Surgical assistant (number, %)						
Consultant	288 (9.6)	162 (11.1)	0.050	232 (10.0)	123 (10.0)	0.001
Other	2720 (90.4)	1299 (88.9)		2091 (90.0)	1113 (90.0)	
Surgical approach (number, %)						
Deltopectoral	2757 (91.7)	1323 (90.6)	0.176	2135 (91.9)	1141 (92.3)	0.071
Deltoid detachment	4 (0.1)	2 (0.1)		3 (0.1)	2 (0.2)	
Other	1 (0.0)	2 (0.2)		1 (0.0)	2 (0.2)	
Posterior	4 (0.1)	8 (0.5)		4 (0.2)	1 (0.1)	
Superior (Mackenzie)	153 (5.1)	104 (7.1)		134 (5.8)	70 (5.7)	
Trans-deltoid	89 (3.0)	22 (1.5)		46 (2.0)	20 (1.6)	
Unit type (number, %)						
NHS	2953 (98.2)	1435 (98.2)	0.004	2283 (98.3)	1215 (98.3)	0.002
Independent	55 (1.8)	26 (1.8)		40 (1.7)	21 (1.7)	
Cases / yr (mean, SD)	10.7 (5.9)	8.6 (5.8)	0.364	9.5 (5.4)	9.2 (6.0)	0.066
Charlson Comorbidity Index(mean, SD)	1.4 (1.8)	1.4 (1.8)	0.018	1.4 (1.7)	1.4 (1.7)	0.013
Deprivation level (number, %)						
Least deprived	990 (33.4)	491 (33.7)	0.079	799 (34.4)	420 (34.0)	0.020
Less deprived	952 (32.2)	436 (30.0)		708 (30.5)	377 (30.5)	
More deprived	699 (23.6)	337 (23.2)		547 (23.5)	288 (23.3)	
Most deprived	320 (10.8)	191 (13.1)		269 (11.6)	151 (12.2)	

Table 5. Characteristics pre- and post-matching, patients age over 75 years.

Model parameters for revision and reoperation in patients aged 60 years and younger

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	0.0086	0.0770
Cons (β_0)	-3.4911	0.8001
Age (β_1)	-0.0148	0.0144
Male (β_2)	-0.2287	0.1755
implant-hemi (β_3)	0.7419	0.1839

Table 6. Model parameters – revision, patients aged 60 years and younger

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	-0.2743	0.0884
cons($\boldsymbol{\beta_0}$)	-3.4562	0.9107
age($\boldsymbol{\beta_1}$)	-0.0116	0.0165
male($\boldsymbol{\beta_2}$)	-0.1812	0.1982
implant-hemi($\boldsymbol{\beta_3}$)	0.7119	0.2051

Table 7. Model parameters – reoperation, patients aged 60 years and younger

Model parameters for revision and reoperation in patients aged 61-75

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	-0.0093	0.0577
cons(β_0)	-2.3988	1.0769
age(β_1)	-0.0364	0.0155
male(β_2)	-0.2432	0.1406
implant-hemi(β_3)	0.7705	0.1351

Table 8. Model parameters – revision, patients aged 61-75 years

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	-0.3712	0.0738
cons(β_0)	-1.9527	1.3465
age(β_1)	-0.0423	0.0194
male(β_2)	0.0052	0.1685
implant-hemi(β_3)	0.7238	0.1732

Table 9. Model parameters – reoperation, patients aged 61-75 years

Model parameters for revision and reoperation in patients aged over 75

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	-0.2516	0.1009
cons(β_0)	-2.9861	2.8146
age(β_1)	-0.1008	0.0354
male(β_2)	0.0674	0.2745
implant-hemi(β_3)	0.4997	0.2294

Table 10. Model parameters – revision, patients aged over 75 years

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	-0.4855	0.1252
cons(β_0)	-0.7671	3.3247
age(β_1)	-0.0595	-0.0595
male(β_2)	0.3546	0.3546
implant-hemi(β_3)	0.9318	0.2918

Table 11. Model parameters – reoperation, patients aged over 75 years

Cost-effectiveness acceptability curve in men

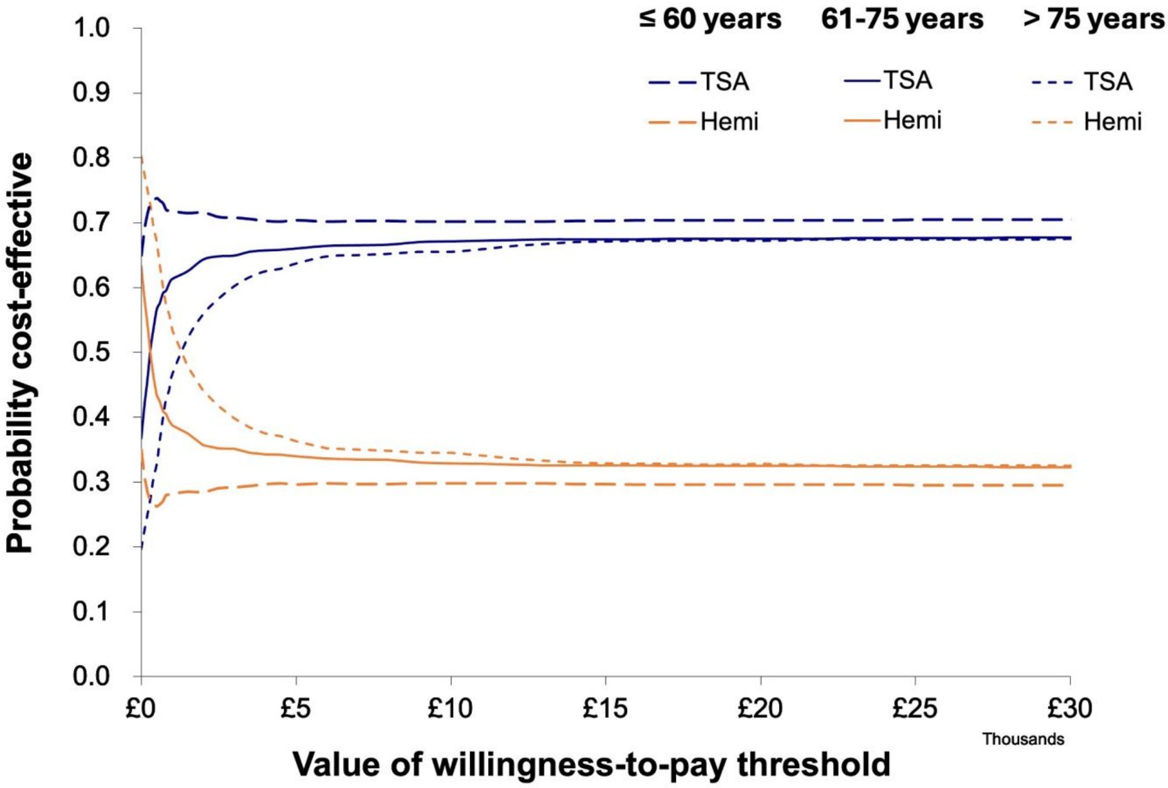

Figure 1. Cost-effectiveness acceptability curve in men.

Cost estimations

Implant costs calculated from the NJR EMBED database

Implant	Mean cost (£)	Standard deviation (£)
TSA	2306.9	381.9
HA	1652.7	535.0

Table 12. Implant costs calculated from the NJR EMBED database.

Difference in the duration of operating time for HA and TSA

An estimation of the duration of a TSA was taken from a large healthcare database (1). The mean length of a TSA was 108.30 minutes (SD 35.60 minutes). Assuming a ratio of 1:1.3 for HA:TSA (table 13) the mean duration of a HA was estimated as 83.31 minutes for an overall mean difference of 24.99 minutes. The standard deviation of the duration of a HA was assumed to be the same as a TSA (35.60 minutes).

Study	Mean operating time (minutes)		Ratio of duration of surgery TSA : HA
	TSA	HA	
Lo et al (2)	157.3	118.4	1.33
Gartsman et al (3)	98	63	1.56
Singh et al (4)	163.3	127.7	1.28
	147.8	121.9	1.21
	114.4	87.1	1.31

Table 13. Duration of operating time TSA and HA.

Duration of TSA (SD) from Testa et al	108.30 min (35.60)
Estimated ratio duration HA to TSA	1 : 1.3
Estimated duration of HA (SD)	83.31 min (24.37)
Difference in mean duration	24.99 min

The cost of an operating theatre per minute was estimated from values submitted to NHS Scotland (5). After accounting for inflation these were £18.61 per minute. The total cost difference between TSA and HA due to theatre time was £18.61*24.99 = £465.11.

Total difference in mean cost

The total difference in mean cost was the difference in the cost of the implants and the costs of theatre time.

Implant mean cost difference	£654.19
Theatre time mean cost difference	£465.11
Total difference	£1119.30

Cost of a HA = reimbursement value - (mean difference / 2) = 6016 – (1119.30/2) = £6575.65

Cost of a TSA = reimbursement value + (mean difference / 2) = 6016 + (1119.30/2) = £5456.35

The standard deviation of the total implant cost for TSA and HA was calculated from the combined variance of the costs of the implant and costs of theatre time.

Overall cost estimations

Implant	Mean cost (£)	Standard deviation (£)
TSA	6575.65	851.7
HA	5456.35	764.8
Revision shoulder (cost code HN86a)	8396	840
Re-revision shoulder (cost code HN86a)	8396	840
Reoperation (cost code HT54B)	2510	251

Table 14. Overall cost estimations

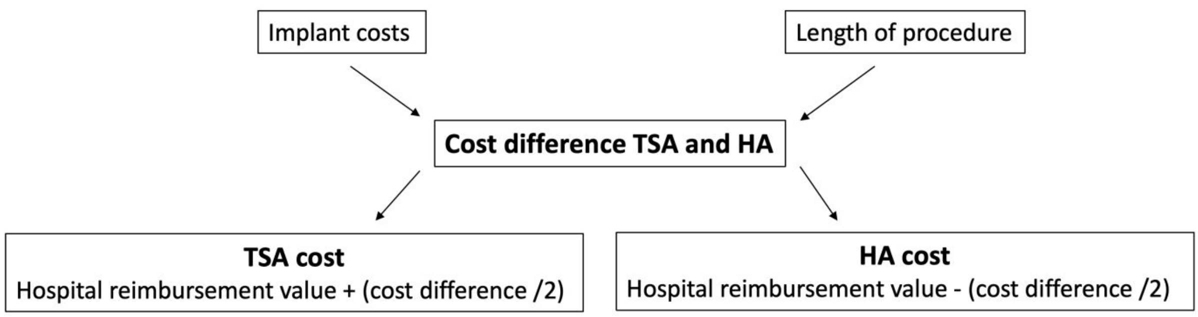

Figure 2. Adjustment of baseline cost, plus additional costs. TSA – total shoulder arthroplasty, HA – Hemiarthroplasty.

Change in costs and QALYs by age for male patients aged 60 years and younger

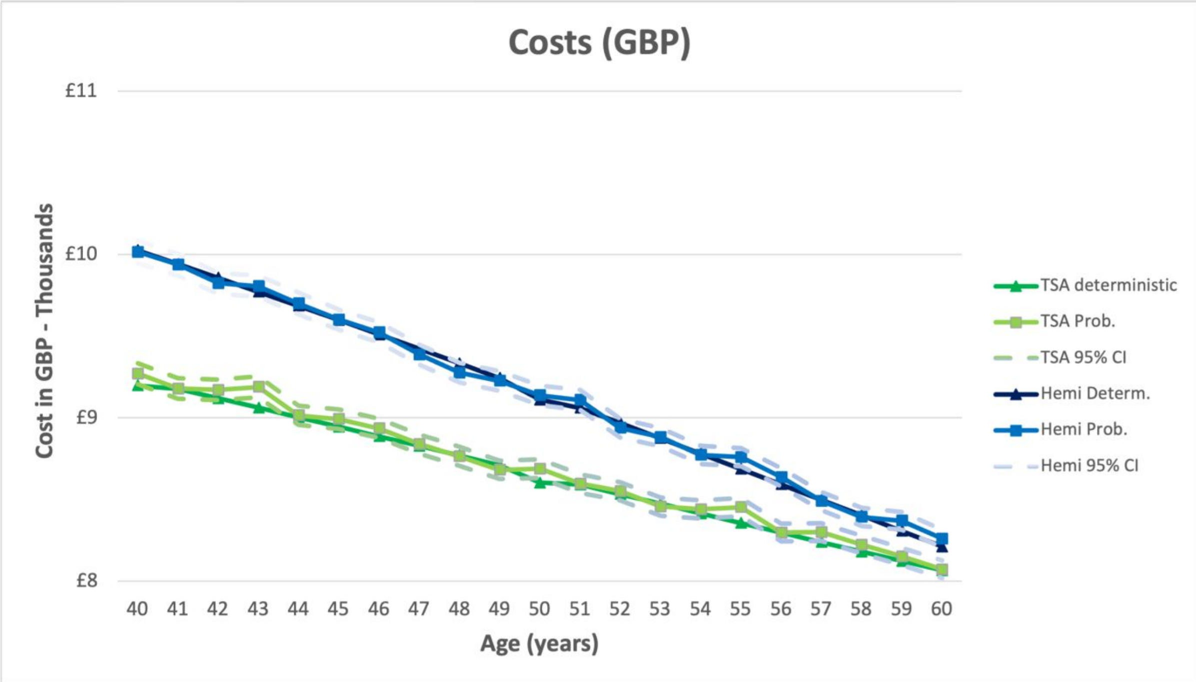

Figure 3. Costs by age for male patients aged 60 years and younger. The same trend was seen in the female cohort.

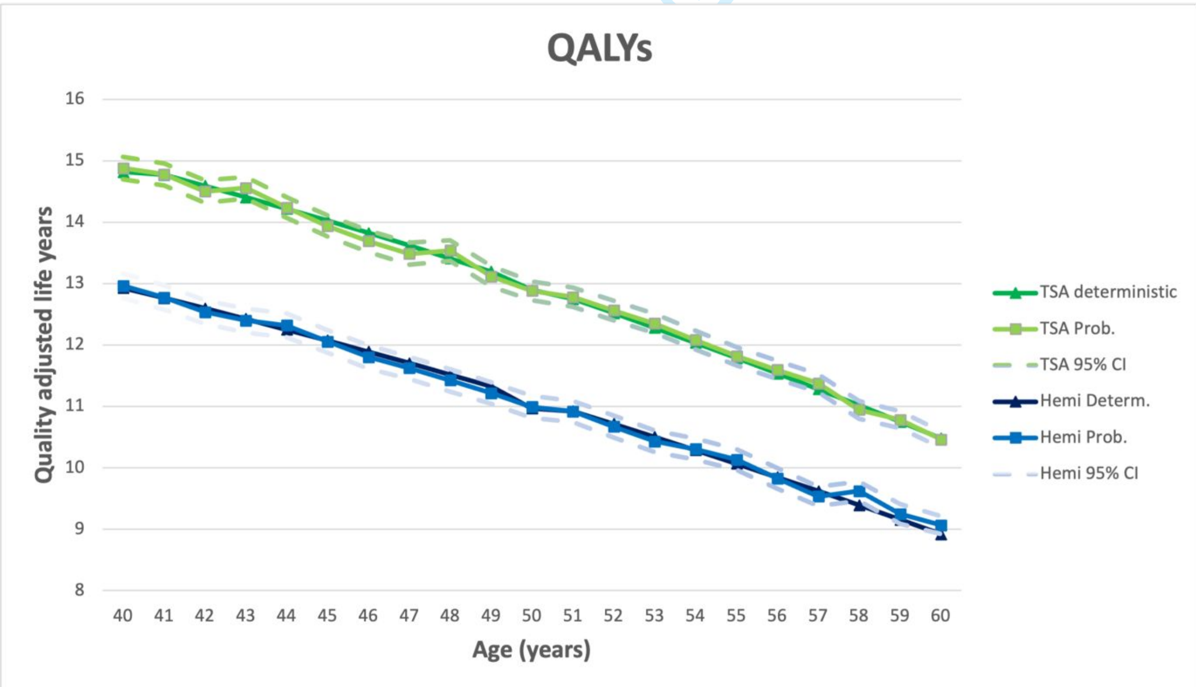

Figure 4. Quality-adjusted life years by age for male patients aged 60 years and younger. The same trend was seen in the female cohort.

CHEERS 2022 Checklist

Topic	No.	Item	Location where item is reported
Title			
	1	Identify the study as an economic evaluation and specify the interventions being compared.	Page 1
Abstract			
	2	Provide a structured summary that highlights context, key methods, results, and alternative analyses.	Pages 2&3
Introduction			
Background and objectives	3	Give the context for the study, the study question, and its practical relevance for decision making in policy or practice.	Pages 4&5
Methods			
Health economic analysis plan	4	Indicate whether a health economic analysis plan was developed and where available.	Submitted to the National Joint Registry
Study population	5	Describe characteristics of the study population (such as age range, demographics, socioeconomic, or clinical characteristics).	Page 6
Setting and location	6	Provide relevant contextual information that may influence findings.	Page 6
Comparators	7	Describe the interventions or strategies being compared and why chosen.	Page 4
Perspective	8	State the perspective(s) adopted by the study and why chosen.	Page 6
Time horizon	9	State the time horizon for the study and why appropriate.	Page 6
Discount rate	10	Report the discount rate(s) and reason chosen.	Page 10
Selection of outcomes	11	Describe what outcomes were used as the measure(s) of benefit(s) and harm(s).	Pages 7-9
Measurement of outcomes	12	Describe how outcomes used to capture benefit(s) and harm(s) were measured.	Pages 7-9
Valuation of outcomes	13	Describe the population and methods used to measure and value outcomes.	Pages 7-11

Topic	No.	Item	Location where item is reported
Measurement and valuation of resources and costs	14	Describe how costs were valued.	Pages 9&10, appendix
Currency, price date, and conversion	15	Report the dates of the estimated resource quantities and unit costs, plus the currency and year of conversion.	Pages 9&10, appendix
Rationale and description of model	16	If modelling is used, describe in detail and why used. Report if the model is publicly available and where it can be accessed.	Pages 6-8, 10&11
Analytics and assumptions	17	Describe any methods for analysing or statistically transforming data, any extrapolation methods, and approaches for validating any model used.	Pages 7-11
Characterising heterogeneity	18	Describe any methods used for estimating how the results of the study vary for subgroups.	Page 11
Characterising distributional effects	19	Describe how impacts are distributed across different individuals or adjustments made to reflect priority populations.	Page 11
Characterising uncertainty	20	Describe methods to characterise any sources of uncertainty in the analysis.	Pages 10&11
Approach to engagement with patients and others affected by the study	21	Describe any approaches to engage patients or service recipients, the general public, communities, or stakeholders (such as clinicians or payers) in the design of the study.	Page 21
Results			
Study parameters	22	Report all analytic inputs (such as values, ranges, references) including uncertainty or distributional assumptions.	Page 14
Summary of main results	23	Report the mean values for the main categories of costs and outcomes of interest and summarise them in the most appropriate overall measure.	Page 12
Effect of uncertainty	24	Describe how uncertainty about analytic judgments, inputs, or projections affect findings. Report the effect of choice of discount rate and time horizon, if applicable.	Pages 12-17
Effect of engagement with patients and others affected by the study	25	Report on any difference patient/service recipient, general public, community, or stakeholder involvement made to the approach or findings of the study	Not reported
Discussion			

Topic	No.	Item	Location where item is reported
Study findings, limitations, generalisability, and current knowledge	26	Report key findings, limitations, ethical or equity considerations not captured, and how these could affect patients, policy, or practice.	Pages 18-20
Other relevant information			
Source of funding	27	Describe how the study was funded and any role of the funder in the identification, design, conduct, and reporting of the analysis	Page 21
Conflicts of interest	28	Report authors conflicts of interest according to journal or International Committee of Medical Journal Editors requirements.	Page 21

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Cost-effectiveness of total shoulder arthroplasty compared to hemiarthroplasty A study using data from the National Joint Registry

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Cost-effectiveness of total shoulder arthroplasty compared to hemiarthroplasty

A study using data from the National Joint Registry

Abstract

Objectives

The aim of this study was to compare the cost-effectiveness of total shoulder arthroplasty (TSA) and hemiarthroplasty (HA) and explore variation by age and gender.

Design

Cost-effectiveness analysis using a lifetime cohort Markov model.

Setting

National population registry data.

Participants

Model parameters were informed by propensity score matched comparisons of TSA and HA in patients with osteoarthritis and an intact rotator cuff using data from the National Joint Registry.

Interventions

Total shoulder arthroplasty and hemiarthroplasty

Primary outcome measures

Quality adjusted life years (QALYs) and healthcare costs for age and gender subgroups. A probabilistic sensitivity analysis was performed.

Results

In all subgroups TSA was more cost effective, with probability of being cost-effective about 70% for TSA versus 30% for HA at any willingness-to-pay threshold above of £1,100 per QALY. TSA was dominant in young patients (≤ 60 years) with a mean cost saving of £463 in men and £658 in women, and a mean QALY gain of 2 in both men and women. In patients aged 61-75 years there was a mean cost saving following HA of £395 in men and £181 in women, while QALYs remained superior following TSA with a 1.3 gain in men and 1.4 women. In the older cohort (> 75 years) the cost difference was highest and the QALY difference lowest; there was a cost saving following HA of £905 in men and £966 in women. The mean QALY gain remained larger after TSA: 0.7 in men and 0.9 in women.

Conclusion

TSA was more cost effective than HA in patients with osteoarthritis. QALYs were superior following TSA in all patient groups. Cost differences varied by age and TSA was dominant in young patients.

Strengths and limitations

- Data from the National Joint Registry was used to inform estimates of health utility and cost in matched groups of total shoulder arthroplasties and hemiarthroplasties.
- The analysis was separated by age (≤ 60 years, 61-75 years, >75 years) and gender.
- Modelling assumptions were necessary to estimate parameters beyond the 9 years of available follow-up.
- There remains a risk of confounding of the relationship between TSA and HA despite matching on propensity scores.

Introduction

Shoulder arthroplasties are increasingly used in the management of glenohumeral osteoarthritis (OA) and the annual costs are substantial [1,2]. Shoulder arthroplasties can be classified into two groups; anatomical and reverse prostheses. Total shoulder arthroplasty (TSA) and hemiarthroplasty (HA) are anatomical prostheses which are used in patients with an intact rotator cuff. Recent population registry studies showed TSA has a lower rate of revision and re-operation and results in superior Patient Reported Outcome Measures (PROMs) compared to HA [3,4]. The risk of revision arthroplasty has been shown to differ by patient age and gender which may result in cost-effectiveness varying in different groups [5]. TSA implants are more expensive and the duration of surgery is longer, however this initial cost difference may have limited impact over the lifetime of the patient.

The management of glenohumeral osteoarthritis in young patients is an area of particular uncertainty. This group has the highest rate of revision and reoperation across the patient's lifetime and the National Institute of Health and Care Excellence (NICE) recommended an economic analysis of TSA vs HA in patients 60 years and under [6]. Economic analyses from North America compared TSA with HA and showed TSA to be more costs effective to varying degrees [7–9]. The parameters were calculated from observational studies and small randomised trials. The data on which to base the utility assumptions were limited and additional costs of reoperations were not included.

The National Joint Registry (NJR) of England, Wales, Northern Ireland, and the Isle of Man includes a large population of anatomical shoulder replacements, data entry commenced in 2012 [10]. Costs paid for components are collected from hospitals across contributing regions of the United Kingdom to provide a more granular estimate of prosthesis costs. These data provide the opportunity to compare anatomical shoulder arthroplasties within age and gender subgroups. The aim of this study was to determine whether TSA or HA was more cost-effective in the management of glenohumeral osteoarthritis in patients with an intact rotator cuff and explore variation by age and gender.

Method

The Consolidated Health Economic Evaluation Reporting Standards 2022 (CHEERS 2022) reporting guideline was used to inform this report (see Supplemental Material) [11].

Population characteristics

The study population for estimation of the revision and re-operation parameters included 14,698 anatomical shoulder arthroplasties from a prior study using NJR data linked to Hospital Episode Statistics (HES) [4]. Arthroplasties performed for an indication other than OA or in patients without an intact rotator cuff were excluded. The mean age of the population was 70.1 (SD 9.6), 31.7% male 68.3% female. The majority had an ASA of II or III (ASA I - 9.0%, II - 67.5%, III - 23.0%, IV - 0.4%). 15.2% were in the most deprived socioeconomic quartile, compared to 29.4% in the least deprived quartile as defined in HES [12]. The population flow diagram is shown in Supplemental Figure 1. The number of arthroplasties in each group and full population characteristics by implant are shown in Supplemental Tables 2-5.

Model structure and perspective

Cost-effectiveness analysis was undertaken for hospital costs with a maximum time horizon of 60 years. The time horizon varied according to the gender and age-specific mortality rate of UK life tables. The age for the cohort entering the model varied from 40 to 90 years. A Markov model with time-dependency was used, the structure of the model is shown in figure 1. The model simulated a 1,000-patient cohort separately for each age and gender. Patients transitioned through a 6-state model according to specified transition probabilities representing time-dependent risks for annual cycles (Supplemental Tables 6 – 11). The model structure separated subgroup heterogeneity from parametric uncertainty using subgroups defined by age group and gender as previously described [13,14].

Figure 1. Model structure. RR1 - revision rate, RR2 - re-operation rate, MR - mortality rate, RRR - re-revision rate, MR - mortality rate.

Patients started with a primary TSA or HA and after a 1 year cycle, moved to one of four different heath states (2) to (5): state (2) remain in the 'successful primary'; state (3) 'revision' of their primary arthroplasty; state (4) 'reoperation'; or reached the final state (6). In the next year cycle, a new health state (5) 're-revision' was added to capture patients requiring a second revision procedure. The rest of the cohort evolved across states (2) to (4), and (6) according to the transition probabilities. Cycles were repeated until all patients had died within the 60-year time horizon.

Outcomes – revision, re-operation, and mortality

The rates of revision and re-operation for HA and TSA were estimated using patient-level data from the NJR. The rates were calculated separately for each of three age groups (i) 60 years or younger, (ii) 61-75 years, and (iii) over 75 years. HA and TSA were matched using propensity scores within each age group to minimise baseline differences in population characteristics using 11 covariates reported previously [4]. These included age, sex, American Society of Anesthesiologists Physical Status Classification System (ASA), rotator cuff condition, primary surgeon seniority, assistant seniority, surgical approach, unit type, mean number of anatomical shoulder arthroplasties performed per year by the responsible consultant, Charlson Comorbidity Index, and deprivation index. The standard mean difference (SMD) were less than 0.1 for each of the 11 co-variates. Characteristics of the subgroup populations and details of the matching process are available in Supplemental Tables 3 - 5.

Follow-up data was available for 9 years and modelling was necessary to extrapolate beyond the available follow-up period. Parametric survival models were specified separately to model the implant duration as time-to-event from primary surgery to revision and reoperation for each implant and subgroup, using the Weibull distribution which allows for increasing or decreasing hazards over time, and it has shown good adjustment to estimate time-to-event clinical outcomes for orthopaedic implants [15]. The transition probabilities for each cycle, t*p(cycle t),* were calculated using the cumulative hazards, *H(t),* according to the methods described below:

$$tp(cycle\ t) = 1 - exp\{H(t-1) - H(t)\}$$

The cumulative hazard for the Weibull distribution is $H(t) = \lambda t^{\kappa}$, and the parameters λ (scale) and κ (shape) were estimated for each subgroup. A Weibull regression was used to estimate the hazards so that the distribution of time-to-event, T, was a function of gender, age, and the whether the prothesis was HA. The hazard function of a Weibull regression was modelled as follows:

$$lnh(t) = lnh0(t) + \beta_0 + \beta_1 age + \beta_1 male + \beta_3 hemiarthroplasty$$

$lnh(t)$ represents the baseline log hazard at time point t, with $h0(t) = \lambda\kappa t^{\kappa-1}$. The effect of HA is measured as a multiplicative effect (additive in the log scale) with the estimated coefficient β_3*,* so that the risk of revision or reoperation is larger for HA than for TSA if $\beta_3 > 0$, with the multiplicative effect measured by $\exp(\beta_3)$.

The rate of re-revision following a successful revision was taken from a meta-analysis [16]. The transition to death was considered as all-cause mortality, measured from the most recent 2018-20 UK life tables, as no deaths were observed during surgery [4]. The life tables present the mortality rate for each age separately for men and women. The mortality rate from age 40 to 100 were used as the transition probabilities to death for each age within each one of the three age groups.

Outcomes – health related quality of life

Oxford shoulder scores (OSSs) from a previous population-level comparative study were used to estimate health-related quality of life (HRQoL) [3,17]. The results were skewed towards the highest score and the median score was used for the purpose of the quality of life estimations [3]. The OSSs were mapped to the EQ-5D-5L [17]. There was minimal change in the OSS from 6 months to 5 years [3]. The model addressed the postoperative recovery period in year 1 by halving the improvement in the EQ-5D-5L value from baseline for the first 6 months followed by the full EQ-5D-5L for the second 6 months. There was no further change in HRQoL after 1 year.

Reports of shoulder scores in revision arthroplasty are very limited [16]. Revision utilities were estimated as 15% less than the combined TSA and HA EQ-5D values. This estimate was made from a combination of data in shoulder and knee arthroplasty [14,16] The same trajectory of improvement in HRQoL in the first year was applied to the revised state. HRQoL following re-revision was assumed to fall by the same proportion as it did from primary to revision arthroplasty. Full details of HRQoL estimations are included in Supplemental Table 1.

Cost estimates

The primary source of information for cost estimation were hospital reimbursement values for shoulder procedures from the 2022/2023 National Tariff Payment System using Healthcare Recourse Group (HRG) codes [18]. The codes do not differentiate between the two types of anatomical shoulder arthroplasty. Two key elements of the total cost of each procedure were used to estimate the difference between primary HA and TSA: length of the procedure and component costs. Costs are described in the British Pound (GBP). Data from the NJR EMBED price benchmarking service was used to calculate the mean price of TSA and HA components [19]. The HRG code HN52 "Very Major Shoulder Procedures for Non-Trauma" was used as the baseline cost for HA and TSA [18]. Theatre time costs were calculated using estimated durations of surgery combined with theatre time cost estimations, the full calculation is available in the Supplemental Figure 3 [20,21]. The total difference in cost was halved and added to the HRG value to estimate the TSA cost and subtracted from the HRG value to estimate HA cost. This meant the mean cost of HA and TSA was equal to the NH52 code value. See Supplemental Tables 14 for further information and the individual values.

The cost of a revision and re-revision arthroplasty was estimated from relevant HRG codes and assumed to be equal between the groups. The model did not include community costs which are minimal compared with the overall cost [14]. A discount rate of 3.5% was applied for costs and health outcomes as recommended by NICE [22].

Parameter distributions for the probabilistic sensitivity analysis

Estimation by subgroups separated demographic heterogeneity from parameter uncertainty, the latter was modelled as a probabilistic sensitivity analysis (PSA). The probability distributions used for the input parameters were informed by the sample means and variability. For the parameters of the Weibull survival models the distributions were multivariate log-normal. To estimate random values from the survival models the raw coefficients (β_0, β_1, β_2, β_3, κ) were assumed to follow a multivariate normal distribution with a correlation structure given by the coefficients from the correlation matrix. Cholesky decomposition of the covariance matrix was performed to simulate the correlated random variates [13]. The parameters of the re-revision rate were assumed to follow a beta distribution. The beta distribution was also used to introduce uncertainty in health utilities on the assumption that no value was less than 0, as observed in the data. The gamma distribution was used to model cost uncertainty due to its favourable properties in this context as a positive and skewed distribution [13].

Final analyses

The model outcomes were estimated separately by gender and age for each of the three age groups: (i) 60 years or younger, (ii) 61-75 years, and (iii) over 75 years. Mean Quality Adjusted Life Year (QALYs) and costs were calculated for TSA and HA and were presented as incremental cost-effectiveness ratios (ICERs). Monte Carlo simulations were used to address parametric uncertainty by generating 1,000 random draws of the assumed statistical distributions for the input parameters. For each one of the three patient subgroups, for a given age and gender, the differential mean costs and QALYs between TSA and HA were calculated. The initial assessment compared these means and established whether one implant dominates the other (if it is less costly and generates more QALYs) or whether it is cost-effective, with incremental costs and incremental QALYs, if the ICER is below the NICE cost-effectiveness threshold established between £20,000-£30,000 per QALY. The probability of either TSA or HA being cost effective was calculated for a range of cost-effectiveness thresholds and the cost-effectiveness acceptability curves (CEAC) were drawn for each patient subgroup. The analyses used to generate the parameter estimates were performed using StataSE v 16 (StataCorp LLC, College Station, TX). The cost effectiveness model was constructed in EXCEL Version 16.80 (Microsoft Corporation, Redmond, Washington). The Markov models were simulated in Excel.

Patient and public involvement

Patients were involved in the design of the wider body of work comparing total shoulder arthroplasty and hemiarthroplasty.

Results

Input parameter values

HA increased the rate of revision and re-operation for the three age groups, more strongly for revision in younger patients than for over 75-year-olds. The estimated mean EQ-5D-5L utility was higher following primary TSA compared to primary HA (Supplemental Table 1). The mean cost of a primary TSA was £6576 compared to £5456 following HA (Supplemental Table 14). Other input parameters were taken from the National Tariff Payment System and the literature. The full tables of input parameters are included in Supplemental Tables 12-14.

Main findings

TSA dominated HA in the young cohort, with TSA resulting in mean cost savings of £463 and a 2.0 QALY gain in men, and a saving of £658 and 2.0 QALY gain in women entering the model at age 50 and representing patients aged 60 years and younger (table 1). The cost savings reversed for the older cohort entering at age 80, representing patients over 75, with HA around £966 less costly than TSA in women, and £905 less costly in men but with 0.9 QALYs less than TSA in women and 0.7 in men. For the middle cohort entering the model at age 67 and representing ages 61-75, there was a cost saving following HA in men and women. TSA resulted in a QALY gain of 1.3 for men and 1.4 for women**.** The probability of TSA being more cost-effective than HA was constant at around 70% for all willingness-to-pay thresholds considered in decision-making in the UK (£20,000 to £30,000 per QALY). The cost-effectiveness planes for each age group in females and males are shown in figures 2 and 3. The results of the cost-effectiveness analyses are presented for each age cohort. Gender subgroup heterogeneity was indistinguishable from parametric uncertainty in the cost-effectiveness (CE) plane therefore the cost-effectiveness acceptability curves (CEAC) are presented for women only (figure 4). The CEAC for men is available in Supplemental Figure 2.

Figure 2. Cost-effectiveness plane: Female 50 – Green, female 67 – Blue, female 80 – Orange. QALYS – Quality Adjusted Life Years.

Figure 3. Cost-effectiveness plane: Male 50 – Green, male 67 – Blue, male 80 – Orange. QALYS – Quality Adjusted Life Years.

	TSA Mean		HA Mean		Difference (HA – TSA)		ICER	
	Cost (£) (95% CI)	QALYs (95% CI)	Cost (£) (95% CI)	QALYs (95% CI)	Costs (£) (95% CI)	QALYs (95% CI)	Cost per QALY (£)	(Prob. TSA cost effective)
Female ≤ 60	9,223 (9,160, 9,287)	13.63 (13.5,13.8)	9,882 (9,817, 9,946)	11.64 (11.5,11.8)	658 (581,735)	-1.99 (-2.2,-1.8)	TSA dominant -331	69%
Male ≤ 60	8,610 (8,553, 8,666)	13.01 (12.9, 13.2)	9,073 (9,012, 9,133)	11.00 (10.8,11.2)	463 (387,538)	-2.01 (-2.3,-1.8)	TSA dominant -230	71%
Female 61-75	7,548 (7,493, 7,602)	9.30 (9.2,9.4)	7,367 (7,316, 7,418)	7.85 (7.7,8.0)	-181 (-253,-109)	-1.44 (-1.6,-1.26)	126	69%
Male 61-75	7,291 (7,238, 7,344)	8.51 (8.4,8.6)	6,895 (6,846, 6,945)	7.25 (7.1,7.4)	-395 (-466,-325)	-1.26 (-1.4,-1.1)	314	68%
Female > 75	6,861 (6,808, 6,914)	5.26 (5.2,5.3)	5,895 (5,848, 5,943)	4.32 (4.2,4.4)	-966 (-1,038, - 893)	-0.94 (-1.1,-0.8)	1,024	70%
Male > 75	6,807 (6,754, 6,859)	4.60 (4.5,4.7)	5,902 (5,854, 5,950)	3.87 (3.8,3.9)	-905 (-976,- 833)	-0.73 (-0.8,-0.6)	1,236	68%

Notes:
The 95% CI is estimated using the standard error of the mean is SEM=SD/$\sqrt{1000}$, where SD is the sample standard deviation of the 1,000 random draws in the PSA.

Table 1. Costs, quality adjusted life years (QALYs), and cost-effectiveness for age and gender subgroups.

Young cohort ≤ 60 years

The slightly smaller costs and QALYs for men compared to women were consistent with lower hazard ratios for revision and re-operation in men along with a shorter lifespan: men accumulate less costs and QALYs during the predicted time horizon. The mean ICERs for women and men aged 50 were negative in the North-West area of the CE plane, with incremental costs and decremental QALYs, therefore TSA was dominant. The rates of revision and re-operation were estimated separately for each age within the cohort. There was a decrease in costs and QALYs as age increased (Supplemental Figures 4 and 5). The difference in costs between TSA and HA decreased with age reflecting the progressive shortening of life span. In contrast, the difference in QALYs remained similar by age.

The CEACs shown in figure 4 imply that TSA had a higher probability of being cost-saving that HA, even at the willingness-to-pay threshold of £0 (indicating cost-savings), due to the larger hazards of revisions and reoperations for HA than TSA whose costs offset the difference in initial cost. The QALY gain reinforces the probability of TSA being dominant over TA.

Middle cohort 61 – 75 years

The overall costs for HA were lower than TSA. The cost of TSA was slightly higher following HA in males and females. TSA rendered more QALYs than HA in both males and females, therefore the ICER was positive but on the South-West quadrant of the CE plane. This quadrant is used for disinvestment decisions (withholding the replacement) if the savings are large – at least more than £20,000-£30,000 according to NICE threshold – which was not this case. To show that HA was not cost effective, the net monetary benefit (NMB) was calculated for females, and it was negative, which showed HA was not cost-effective:

$$NMB = Threshold * \Delta QALY - \Delta Cost = £20{,}000 * (-1.44) - (-181) = -28{,}619$$

At the willingness-to-pay threshold of £0, there was cross-over; both HA and TSA had the same probability of being cost saving. The hazards of revision and re-operation were still larger for HA than TSA, however the middle cohort accumulated less years of costs.

Older cohort over 75 years

The older cohort accumulated the fewest years of costs and QALYs. The hazards of revision and re-operation remained larger for HA than TSA but the greatest cost saving following HA was shown in this cohort. For both female and male aged 80, HA was less costly than TSA because the HA prosthesis is cheaper and the incremental costs from more reoperations and revisions were negligible. However, the savings did not justify a disinvestment in TSA or replacing TSA by HA. Differential QALYs favour TSA, and the NMB was negative (NMB= 20,000*(-0.94)-(-966) =-17,834).

At the willingness-to-pay threshold of £0, HA was more likely to be cost saving. At a threshold of £1100 – £1250 per QALY, there was cross-over in the probability of HA and TSA being cost-effective, and TSA is more cost-effective, with probability up to 68% for men for a threshold over £1250 per QALY.

Figure 4. Cost-effectiveness acceptability curves in women.

Discussion

Principal findings

The results showed cost effectiveness was likely to be higher following TSA for all age subgroups at a threshold of £20,000-£30,000 per QALY. QALYs were higher for TSA in all age groups. In the young cohort costs were higher following HA. Despite the lower costs of HA implants and shorter theatre time, this was offset by the additional costs of revision/re-operation. In the older cohort TSA was more expensive than HA because the higher initial costs were not offset by the lower overall rate of revision and reoperation after TSA during patients' shorter lifetime. The sensitivity analyses accounted for the uncertainty in the estimates and within each age group the probability of cost-effectiveness was approximately 0.7 for TSA at current NICE threshold of £20,000-£30,000 per QALY. There is particular interest in the cost-effectiveness of anatomical shoulder replacements in young patients [6]. TSA was dominant in patients 60 years and younger at a willingness to pay threshold of £0, primarily due to the large difference in revision rate and longer lifetime of patients in this subgroup, implying TSA is cost saving compared to HA. Postoperative shoulder function may determine whether patients can return to work [23]. As the number of shoulder arthroplasties performed each year increases, including in young patients, the loss of productivity due to the additional time required off work should be considered. This further supports the economic arguments for TSA given the superior post-operative shoulder function.

Strengths and limitations

This is the first study to investigate cost-effectiveness in anatomical shoulder replacements using parameter estimates based on National registry data from the U.K., and the first to investigate cost-effectiveness in young patients. Age is an important driver of revision rate, and the analysis was split into 3 age subgroups to better represent subgroup differences in cost-effectiveness across the population. Confounding by indication remained a concern and arthroplasties within each age group

were matched on propensity scores calculated from 11 important variables to minimise the risk of baseline differences between the groups. The study was limited to patients with osteoarthritis and an intact rotator cuff. Revision and re-operation estimates were based on models extrapolated from registry data with a maximum follow-up of 9 years. The sensitivity analysis demonstrated uncertainty in the results. The largest uncertainty was in the utility and cost estimates. The uncertainty in implant survival was smaller.

Modelling assumptions were necessary. Individuals could not undergo revision or re-operation within the first year following the primary procedure, and revision and re-operation could not occur within the same year. We assumed there was no change in utility after the first 6 months, and the annual utility was averaged accordingly. The OSS may continue to improve beyond 6 months after TSA, and the ceiling affect shown in the OSS at 5 years may result in an underestimate of the improvement. The same trajectory of utility following revision surgery was assumed. The utility estimates required transformation of the OSS to the EQ5D. Despite a mapping algorithm based on high quality data, this introduced additional uncertainty. Revision utilities were estimated by reducing the combined primary utility by 15%. In a prior systematic review shoulder scores were collected following revision arthroplasty but only one small study of 15 patients reported OSSs following TSA and none following HA [16]. No mapping studies are available to estimate the EQ5D from other shoulder scores.

The cost estimates centred around hospital reimbursement values to improve the generalisability of the results. The cost of theatre time will vary by unit, a range of values are reported, and there is uncertainty among hospital managers [24]. The value selected for this work was taken from pooled data from NHS Scotland [21]. A median value of implant costs nationally was used to ensure they were generalisable compared to the alternative of relying on procurement costs of a limited number of implants from a single, or small number of hospitals. A single reimbursement code was used for each of the re-operation and revision procedures representing patients with moderate co-morbidities. The standard deviation of the cost estimates for re-operation and revision were assumed to be 10% of the cost of the procedure. Post-operative mortality was assumed to be equivalent to age and gender specific mortality recorded nationally, no evidence could be found to contradict this assumption. Previous work showed there was no difference between the implants at 1 year [4]. The national life tables were considered a more accurate predictor of death than summary estimates generated from a relatively small population for this rare outcome. If the rate of death was higher following surgery than in the general population, this may overestimate the cost-effectiveness of both implants.

Comparison to other studies

Prior work comparing the cost-effectiveness of HA and TSA, is from North America [7–9]. The most recent study by Lapner et al showed TSA was more cost-effective [7]. The results were more strongly in favour of TSA than in this study, which may be a product of the difference in North American costs compared to U.K. costs, and the revision and utility estimates. The utility assumptions for HA were based on patients following proximal humerus fractures which may underestimate the effect of HA [7]. The earlier studies used more limited datasets and showed superiority of TSA to varying degrees [8,9]. Given the sensitivity of the models to revision rate shown in this study, the quality of the data used to estimate implant survival is particularly important.

The use of HA has declined however it continues to be used, most commonly in younger patients, where there is particular uncertainty about the most appropriate implant [6]. Multiple factors are considered when selecting implants for a patient. Prior work has demonstrated a higher revision rate following HA and inferior shoulder scores [3,4]. This study showed TSA was cost effective in the management of glenohumeral osteoarthritis, and the superiority of TSA was most clear in the younger cohort, further supporting the use of TSA in patients with osteoarthritis and an intact rotator cuff.

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Ethical approval

The study used pseudo-anonymised data from a national clinical registry. The Health Research Authority guidance confirmed ethical approval was not required.

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Competing interests

PR receives funding for alternative work from Mathys and Orthopaedic Research UK. AR receives funding for alternative work from the NIHR, AO UK&I and DePuy J&J Ltd. AR is a member of the NIHR i4i funding committee. AD, BZ, SS, AL, and MVB have no competing interests.

Data sharing arrangement

Original data can be requested from the National Joint Registry

Author contributions

Andrew Davies is the guarantor

AD	Conceptualisation, methodology, analysis, writing – original draft.
BZ	Data curation, methodology, analysis, writing – original draft
SS	Conceptualisation, analysis, writing – review and editing
AL	Methodology, analysis, supervision, writing – review and editing
MVB	Methodology, analysis, writing – review and editing
AR	Conceptualisation, supervision, writing – review and editing
PR	Conceptualisation, supervision, writing – review and editing

Figure 1. Model structure. RR1 - revision rate, RR2 - re-operation rate, MR - mortality rate, RRR - re-revision rate, MR - mortality rate.

Figure 2. Cost-effectiveness plane: Female 50 – Green, female 67 – Blue, female 80 – Orange. QALYS – Quality Adjusted Life Years.

Figure 3. Cost-effectiveness plane: Male 50 – Green, male 67 – Blue, male 80 – Orange. QALYS – Quality Adjusted Life Years.

Figure 4. Cost-effectiveness acceptability curve in women.

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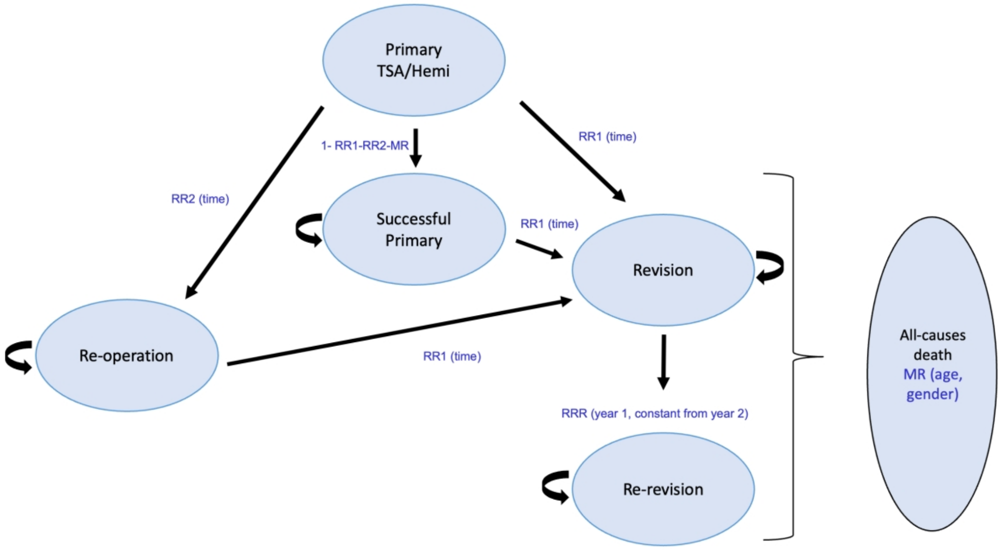

Figure 1. Model structure. RR1 - revision rate, RR2 - re-operation rate, MR - mortality rate, RRR - re-revision rate, MR - mortality rate.

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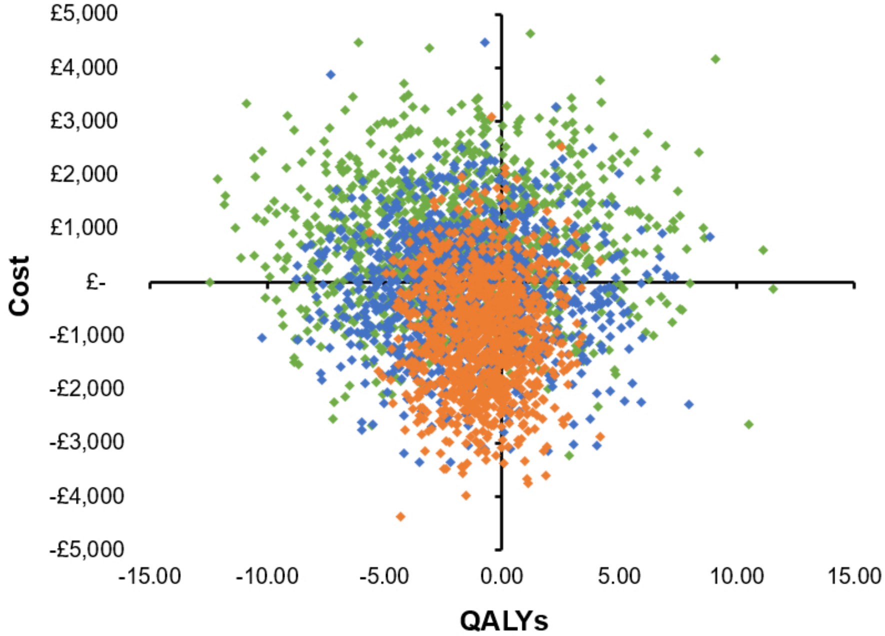

Figure 2. Cost-effectiveness plane: Female 50 – Green, female 67 – Blue, female 80 – Orange. QALYS – Quality Adjusted Life Years.

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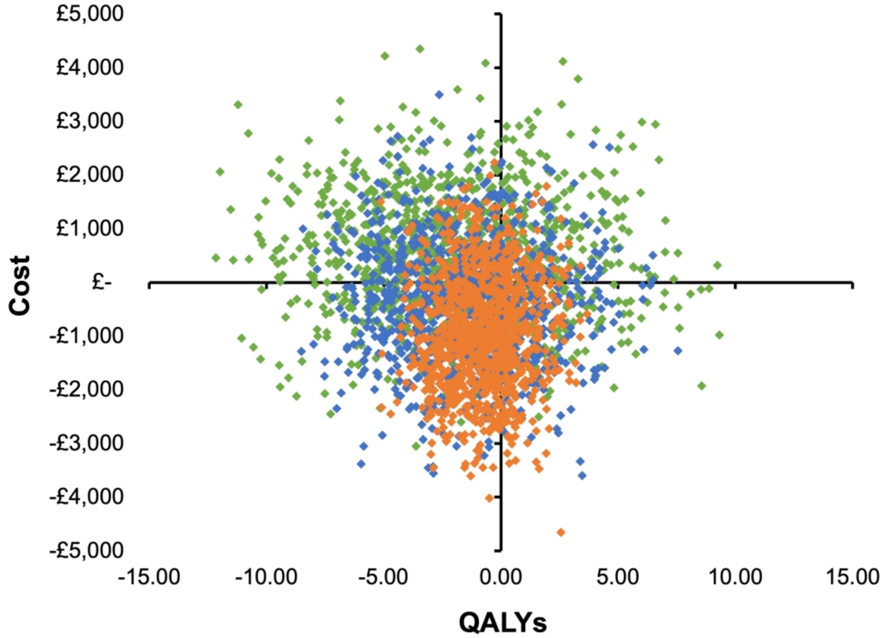

Figure 3. Cost-effectiveness plane: Male 50 – Green, male 67 – Blue, male 80 – Orange. QALYS – Quality Adjusted Life Years.

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Figure 4. Cost-effectiveness acceptability curve in women.

Appendix

Model parameters – health utility

Prosthesis	Procedure	EQ-5D-5L	Standard deviation
TSA	Pre-operative	0.34	
	Success Primary	0.76	0.18
	Success Revision	0.61	0.18
	Recovery Primary	0.66	0.18
	Recovery Revision	0.54	0.18
	Re-revision	0.54	0.18
	Pre-operative	0.34	0.18
Hemi	Pre-operative	0.35	
	Success Primary	0.64	0.22
	Success Revision	0.61	0.22
	Recovery Primary	0.58	0.22
	Recovery Revision	0.54	0.22
	Re-revision	0.54	0.18
	Pre-operative	0.35	0.18

Table 1. EQ-5D-5L utility scores.

Number of shoulders arthroplasties in each age group

Age group	Pre-matching		Post-matching	
	TSA	HA	TSA	HA
≤ 60 years	1471	746	1177	623
61 – 75 years	6002	2010	3714	1889
> 75 years	3008	1461	2323	1236

Table 2. Number of shoulder arthroplasties in each age group.

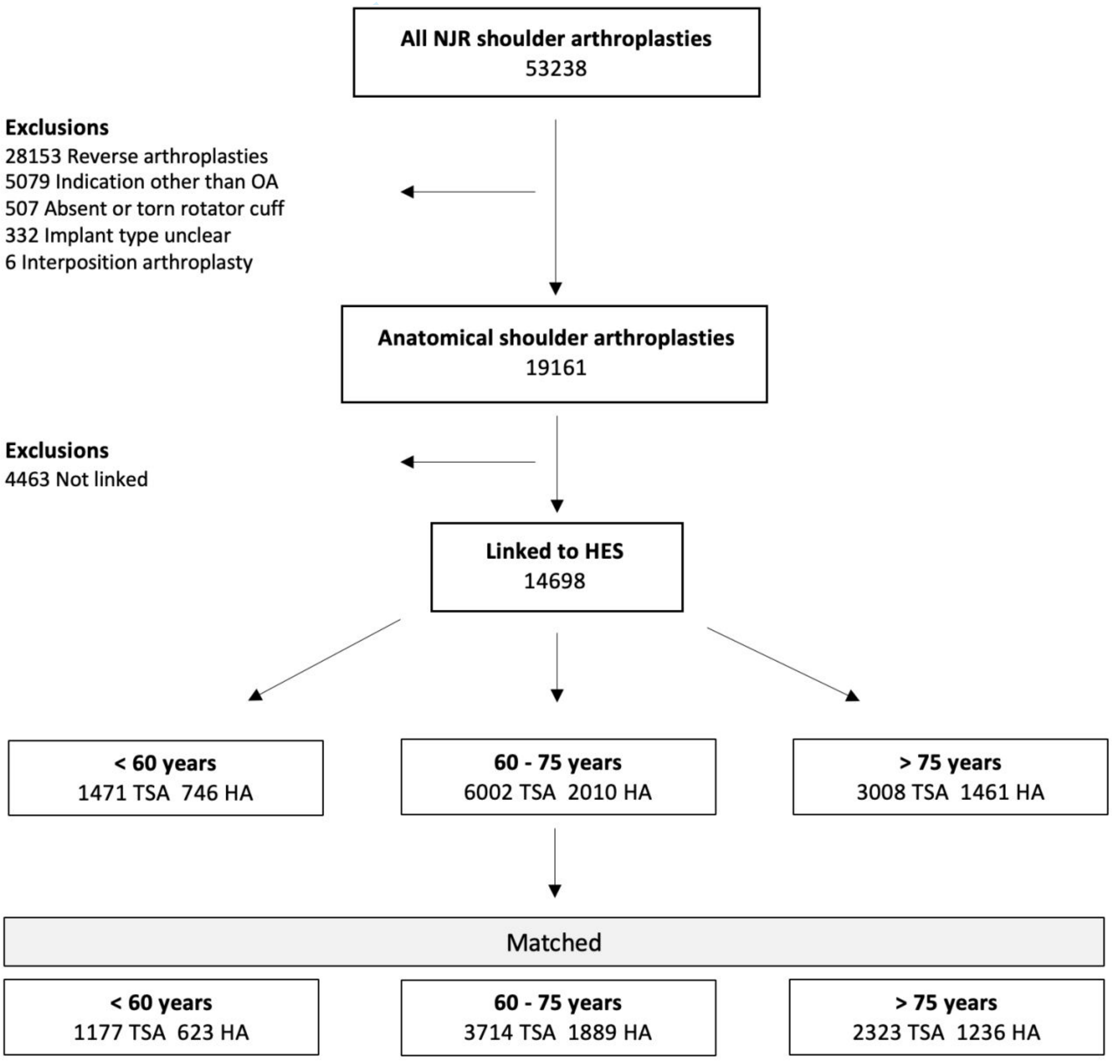

Figure 1. Study flow diagram. Adapted with consent from Davies et al (1).

Matching process

Components of the matching process were varied to achieve the optimal match as defined by the lowest standardised mean difference (SMD) between each variable pre- and post-matching. The lowest SMDs were achieved when patients were matched on the linear predictor (log odds of the propensity score) using a ratio of 1 HA to 2 TSA, greedy matching without replacement and a calliper width of 0.2.

Characteristics pre and post matching – subgroup aged 60 years or less

	Pre-matching			Post-matching		
Characteristic	TSA	HA	SMD	TSA	HA	SMD
Age (mean, SD)	54.5 (5.4)	52.0 (7.4)	0.382	53.8 (5.7)	53.6 (5.7)	0.042
Gender (number, %)						
Male	767 (52.1)	481 (64.5)	0.252	681 (57.9)	382 (61.3)	0.071
Female	704 (47.9)	265 (35.5)		496 (42.1)	241 (38.7)	
ASA (number, %)						
I	283 (19.2)	203 (27.2)	0.197	248 (21.1)	144 (23.1)	0.054
II	950 (64.6)	422 (56.6)		724 (61.5)	377 (60.5)	
III	230 (15.6)	118 (15.8)		200 (17.0)	99 (15.9)	
IV	8 (0.5)	3 (0.4)		5 (0.4)	3 (0.5)	
Rotator cuff (number, %)						
Attenuated/normal	1460 (99.3)	730 (97.9)	0.117	1166 (99.1)	617 (99.0)	0.003
Repaired	11 (0.7)	16 (2.1)		11 (0.9)	6 (1.0)	
Operating surgeon (number, %)						
Consultant	1369 (93.1)	704 (94.4)	0.168	1117 (94.9)	593 (95.2)	0.016
SpR/ST3-ST8	46 (3.1)	30 (4.0)		39 (3.3)	20 (3.2)	
Speciality doctor	31 (2.1)	4 (0.5)		8 (0.7)	4 (0.6)	
F1-ST2	0 (0.0)	1 (0.1)		0 (0.0)	0 (0.0)	
Other	25 (1.7)	7 (0.9)		13 (1.1)	6 (1.0)	
Surgical assistant (number, %)						
Consultant	121 (8.2)	59 (7.9)	0.012	95 (8.1)	45 (7.2)	0.032
Other	1350 (91.8)	687 (92.1)		1082 (91.9)	578 (92.8)	
Surgical approach (number, %)						
Deltopectoral	1369 (93.1)	704 (94.4)	0.213	1096 (93.1)	573 (92.0)	0.071
Deltoid detachment	4 (0.3)	1 (0.1)		1 (0.1)	1 (0.2)	
Other	2 (0.1)	0 (0.0)		0 (0.0)	0 (0.0)	
Posterior	3 (0.2)	2 (0.3)		3 (0.3)	2 (0.3)	
Superior (Mackenzie)	69 (4.7)	63 (8.4)		66 (5.6)	40 (6.4)	
Trans-deltoid	24 (1.6)	13 (1.7)		11 (0.9)	7 (1.1)	
Unit type (number, %)						
NHS	1440 (97.9)	735 (98.5)	0.048	1159 (98.5)	613 (98.4)	0.006
Independent	31 (2.1)	11 (1.5)		18 (1.5)	10 (1.6)	
Cases / yr (mean, SD)	9.3 (5.5)	8.2 (4.9)	0.198	8.5 (5.0)	8.4 (5.0)	0.033
Charlson Comorbidity Index(mean, SD)	0.8 (1.3)	0.8 (1.3)	0.006	0.8 (1.3)	0.8 (1.3)	0.025
Deprivation level (number, %)						
Least deprived	314 (21.6)	180 (24.3)	0.080	268 (22.8)	149 (23.9)	0.032
Less deprived	401 (27.6)	185 (25.0)		314 (26.7)	160 (25.7)	
More deprived	391 (26.9)	205 (27.7)		323 (27.4)	172 (27.6)	
Most deprived	349 (24.0)	170 (23.0)		272 (23.1)	142 (22.8)	

Table 3. Characteristics pre- and post-matching, patients age 60 years or less.

Characteristics pre and post matching – subgroup aged 61-75 years

	Pre-matching			Post-matching		
Characteristic	TSA	HA	SMD	TSA	HA	SMD
Age (mean, SD)	69.0 (4.0)	69.0 (4.1)	0.003	69.0 (4.1)	68.9 (4.1)	0.013
Gender (number, %)						
Male	1913 (31.9)	692 (34.4)	0.054	1262 (34.0)	652 (34.5)	0.011
Female	4089 (68.1)	1318 (65.6)		2452 (66.0)	1237 (65.5)	
ASA (number, %)						
I	480 (8.0)	170 (8.5)	0.077	313 (8.4)	157 (8.3)	0.019
II	4252 (70.8)	1369 (68.1)		2526 (68.0)	1290 (68.3)	
III	1259 (21.0)	461 (22.9)		865 (23.3)	435 (23.0)	
IV	11 (0.2)	10 (0.5)		10 (0.3)	7 (0.4)	
Rotator cuff (number, %)						
Attenuated/normal	5945 (99.1)	1961 (97.6)	0.116	3660 (98.5)	1865 (98.7)	0.016
Repaired	57 (1.5)	49 (2.4)		54 (1.5)	24 (1.3)	
Operating surgeon (number, %)						
Consultant	5465 (91.1)	1838 (91.4)	0.077	3404 (91.7)	1735 (91.8)	0.009
SpR/ST3-ST8	120 (2.0)	23 (1.1)		205 (5.5)	101 (5.3)	
Speciality doctor	289 (4.8)	111 (5.5)		60 (1.6)	31 (1.6)	
Other	128 (2.1)	38 (1.9)		45 (1.2)	22 (1.2)	
Surgical assistant (number, %)						
Consultant	540 (9.0)	192 (9.6)	0.019	377 (9.1)	177 (9.4)	0.010
Other	5462 (91.0)	1818 (90.4)		3377 (90.9)	1712 (90.6)	
Surgical approach (number, %)						
Deltopectoral	5569 (92.8)	1771 (88.1)	0.189	3379 (91.0)	1733 (91.7)	0.045
Deltoid detachment	9 (0.1)	3 (0.1)		7 (0.2)	3 (0.2)	
Other	12 (0.2)	4 (0.2)		7 (0.2)	4 (0.2)	
Posterior	10 (0.2)	6 (0.3)		8 (0.2)	5 (0.3)	
Superior (Mackenzie)	283 (4.7)	180 (9.0)		246 (6.6)	108 (5.7)	
Trans-deltoid	119 (2.0)	46 (2.3)		67 (1.8)	36 (1.9)	
Unit type (number, %)						
NHS	5901 (98.3)	1985 (98.8)	0.037	3669 (98.8)	1864 (98.7)	0.010
Independent	101 (1.7)	25 (1.2)		45 (1.2)	25 (1.3)	
Cases / yr (mean, SD)	9.8 (5.6)	8.2 (5.3)	0.304	8.5 (5.1)	8.2 (5.1)	0.060
Charlson Comorbidity Index(mean, SD)	1.1 (1.6)	1.1 (1.5)	0.001	1.1 (1.5)	1.1 (1.5)	0.009
Deprivation level (number, %)						
Least deprived	1655 (28.0)	611 (30.5)	0.073	1114 (30.0)	581 (30.8)	0.022
Less deprived	1945 (32.9)	598 (29.9)		1096 (29.5)	560 (29.6)	
More deprived	1417 (24.0)	483 (24.1)		917 (24.7)	451 (23.9)	
Most deprived	887 (15.0)	311 (15.5)		587 (15.8)	297 (15.7)	

Table 4. Characteristics pre- and post-matching, patients age 61-75 years.

Characteristics pre and post matching – subgroup aged > 75 years

	Pre-matching			Post-matching		
Characteristic	TSA	HA	SMD	TSA	HA	SMD
Age (mean, SD)	80.1 (3.5)	80.9 (3.9)	0.221	80.4 (3.6)	80.4 (3.6)	0.016
Gender (number, %)						
Male	584 (19.4)	236 (16.2)	0.085	410 (17.6)	220 (17.8)	0.004
Female	2424 (80.6)	1225 (83.8)		1913 (82.4)	1016 (82.2)	
ASA (number, %)						
I	120 (4.0)	70 (4.8)	0.092	103 (4.4)	57 (4.6)	0.019
II	2013 (66.9)	914 (62.6)		1492 (64.2)	797 (64.5)	
III	854 (28.4)	466 (31.9)		712 (30.7)	372 (30.1)	
IV	21 (0.7)	11 (0.8)		16 (0.7)	10 (0.8)	
Rotator cuff (number, %)						
Attenuated/normal	2966 (98.6)	1429 (97.8)	0.060	2284 (98.3)	1216 (98.4)	0.005
Repaired	42 (1.4)	32 (2.2)		39 (1.7)	20 (1.6)	
Operating surgeon (number, %)						
Consultant	2666 (88.6)	1308 (89.5)	0.163	2076 (89.4)	1118 (90.5)	0.069
SpR/ST3-ST8	71 (2.4)	11 (0.8)		133 (5.7)	74 (6.0)	
Speciality doctor	154 (5.1)	102 (7.0)		82 (3.5)	33 (2.7)	
Other	117 (3.9)	40 (2.7)		32 (1.4)	11 (0.9)	
Surgical assistant (number, %)						
Consultant	288 (9.6)	162 (11.1)	0.050	232 (10.0)	123 (10.0)	0.001
Other	2720 (90.4)	1299 (88.9)		2091 (90.0)	1113 (90.0)	
Surgical approach (number, %)						
Deltopectoral	2757 (91.7)	1323 (90.6)	0.176	2135 (91.9)	1141 (92.3)	0.071
Deltoid detachment	4 (0.1)	2 (0.1)		3 (0.1)	2 (0.2)	
Other	1 (0.0)	2 (0.2)		1 (0.0)	2 (0.2)	
Posterior	4 (0.1)	8 (0.5)		4 (0.2)	1 (0.1)	
Superior (Mackenzie)	153 (5.1)	104 (7.1)		134 (5.8)	70 (5.7)	
Trans-deltoid	89 (3.0)	22 (1.5)		46 (2.0)	20 (1.6)	
Unit type (number, %)						
NHS	2953 (98.2)	1435 (98.2)	0.004	2283 (98.3)	1215 (98.3)	0.002
Independent	55 (1.8)	26 (1.8)		40 (1.7)	21 (1.7)	
Cases / yr (mean, SD)	10.7 (5.9)	8.6 (5.8)	0.364	9.5 (5.4)	9.2 (6.0)	0.066
Charlson Comorbidity Index(mean, SD)	1.4 (1.8)	1.4 (1.8)	0.018	1.4 (1.7)	1.4 (1.7)	0.013
Deprivation level (number, %)						
Least deprived	990 (33.4)	491 (33.7)	0.079	799 (34.4)	420 (34.0)	0.020
Less deprived	952 (32.2)	436 (30.0)		708 (30.5)	377 (30.5)	
More deprived	699 (23.6)	337 (23.2)		547 (23.5)	288 (23.3)	
Most deprived	320 (10.8)	191 (13.1)		269 (11.6)	151 (12.2)	

Table 5. Characteristics pre- and post-matching, patients age over 75 years.

Model parameters for revision and reoperation in patients aged 60 years and younger – Weibull regression relative hazard

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	0.0086	0.0770
Cons (β_0)	-3.4911	0.8001
Age (β_1)	-0.0148	0.0144
Male (β_2)	-0.2287	0.1755
implant-hemi (β_3)	0.7419	0.1839

Table 6. Model parameters – revision, patients aged 60 years and younger

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	-0.2743	0.0884
cons($\boldsymbol{\beta_0}$)	-3.4562	0.9107
age($\boldsymbol{\beta_1}$)	-0.0116	0.0165
male($\boldsymbol{\beta_2}$)	-0.1812	0.1982
implant-hemi($\boldsymbol{\beta_3}$)	0.7119	0.2051

Table 7. Model parameters – reoperation, patients aged 60 years and younger

Model parameters for revision and reoperation in patients aged 61-75 – Weibull regression relative hazard

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	-0.0093	0.0577
cons(β_0)	-2.3988	1.0769
age(β_1)	-0.0364	0.0155
male(β_2)	-0.2432	0.1406
implant-hemi(β_3)	0.7705	0.1351

Table 8. Model parameters – revision, patients aged 61-75 years

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	-0.3712	0.0738
cons(β_0)	-1.9527	1.3465
age(β_1)	-0.0423	0.0194
male(β_2)	0.0052	0.1685
implant-hemi(β_3)	0.7238	0.1732

Table 9. Model parameters – reoperation, patients aged 61-75 years

Model parameters for revision and reoperation in patients aged over 75 – Weibull regression relative hazard

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	-0.2516	0.1009
cons(β_0)	-2.9861	2.8146
age(β_1)	-0.1008	0.0354
male(β_2)	0.0674	0.2745
implant-hemi(β_3)	0.4997	0.2294

Table 10. Model parameters – revision, patients aged over 75 years

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	-0.4855	0.1252
cons(β_0)	-0.7671	3.3247
age(β_1)	-0.0595	0.0285
male(β_2)	0.3546	0.1524
implant-hemi(β_3)	0.9318	0.2918

Table 11. Model parameters – reoperation, patients aged over 75 years

Cost-effectiveness acceptability curve in men

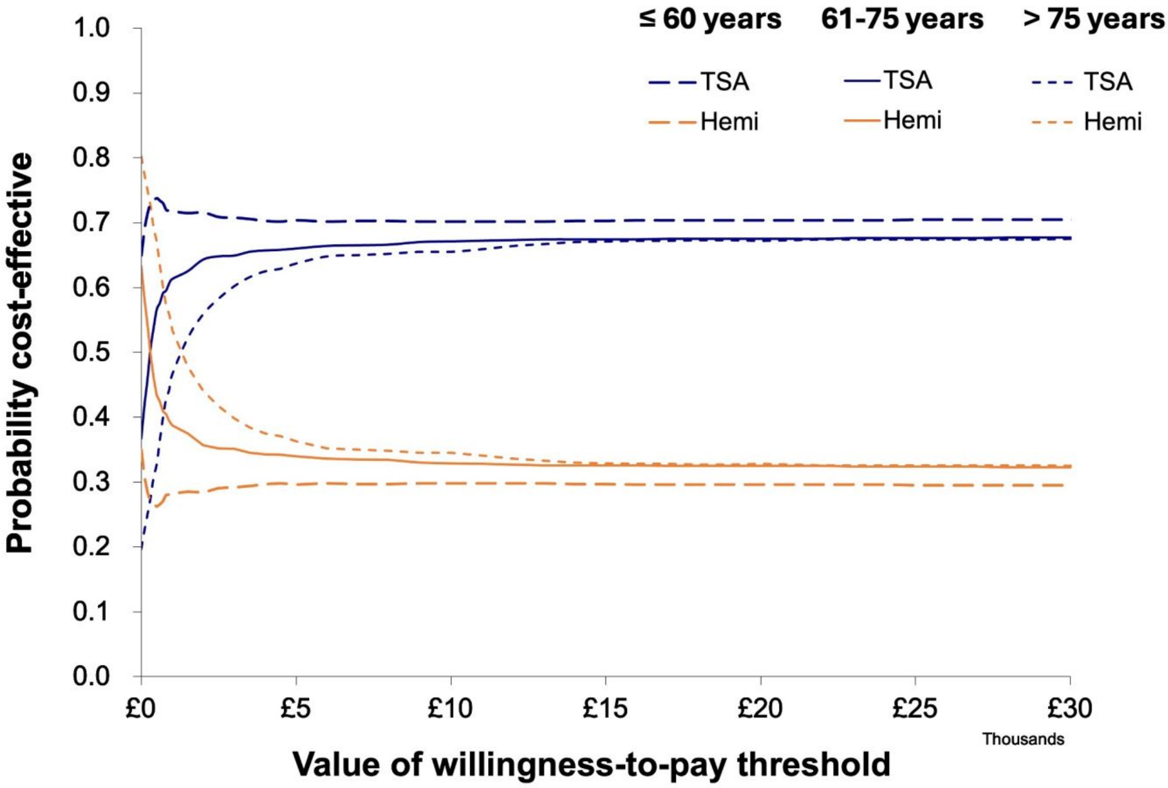

Figure 2. Cost-effectiveness acceptability curve in men.

Cost estimations

Implant costs calculated from the NJR EMBED database

Implant	Mean cost (£)	Standard deviation (£)
TSA	2306.9	381.9
HA	1652.7	535.0

Table 12. Implant costs calculated from the NJR EMBED database.

Difference in the duration of operating time for HA and TSA

An estimation of the duration of a TSA was taken from a large healthcare database (2). The mean length of a TSA was 108.30 minutes (SD 35.60 minutes). Assuming a ratio of 1:1.3 for HA:TSA (table 13) the mean duration of a HA was estimated as 83.31 minutes for an overall mean difference of 24.99 minutes. The standard deviation of the duration of a HA was assumed to be the same as a TSA (35.60 minutes).

Study	Mean operating time (minutes)		Ratio of duration of surgery TSA : HA
	TSA	HA	
Lo et al (3)	157.3	118.4	1.33
Gartsman et al (4)	98	63	1.56
Singh et al (5)	163.3	127.7	1.28
	147.8	121.9	1.21
	114.4	87.1	1.31

Table 13. Duration of operating time TSA and HA.

Duration of TSA (SD) from Testa et al	108.30 min (35.60)
Estimated ratio duration HA to TSA	1 : 1.3
Estimated duration of HA (SD)	83.31 min (24.37)
Difference in mean duration	24.99 min

The cost of an operating theatre per minute was estimated from values submitted to NHS Scotland (6). After accounting for inflation these were £18.61 per minute. The total cost difference between TSA and HA due to theatre time was £18.61*24.99 = £465.11.

Total difference in mean cost

The total difference in mean cost was the difference in the cost of the implants and the costs of theatre time.

Implant mean cost difference	£654.19
Theatre time mean cost difference	£465.11
Total difference	£1119.30

Cost of a HA = reimbursement value - (mean difference / 2) = 6016 – (1119.30/2) = £6575.65

Cost of a TSA = reimbursement value + (mean difference / 2) = 6016 + (1119.30/2) = £5456.35

The standard deviation of the total implant cost for TSA and HA was calculated from the combined variance of the costs of the implant and costs of theatre time.

Overall cost estimations

Implant	Mean cost (£)	Standard deviation (£)
TSA	6575.65	851.7
HA	5456.35	764.8
Revision shoulder (cost code HN86a)	8396	840
Re-revision shoulder (cost code HN86a)	8396	840
Reoperation (cost code HT54B)	2510	251

Table 14. Overall cost estimations

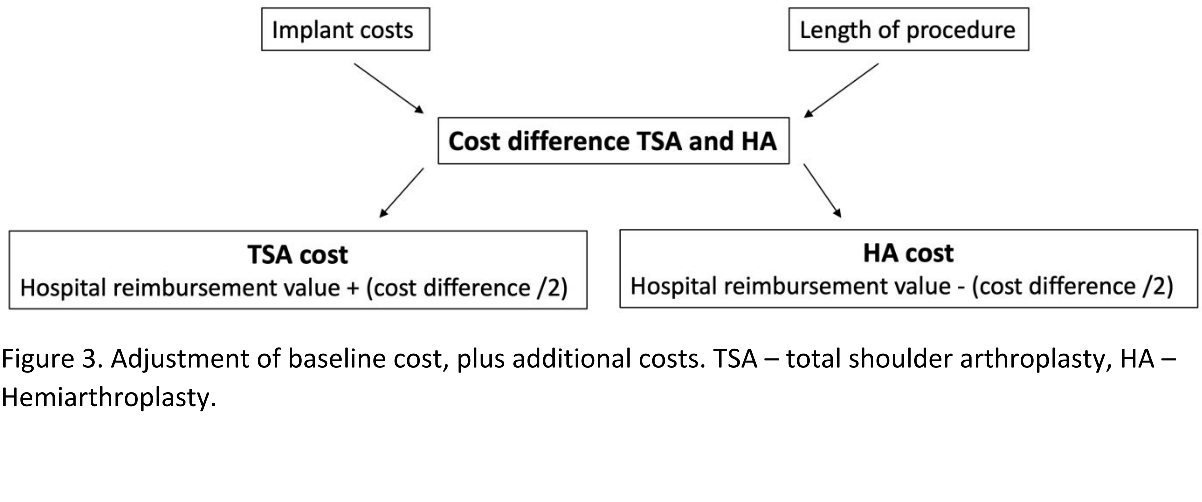

Figure 3. Adjustment of baseline cost, plus additional costs. TSA – total shoulder arthroplasty, HA – Hemiarthroplasty.

Change in costs and QALYs by age for male patients aged 60 years and younger

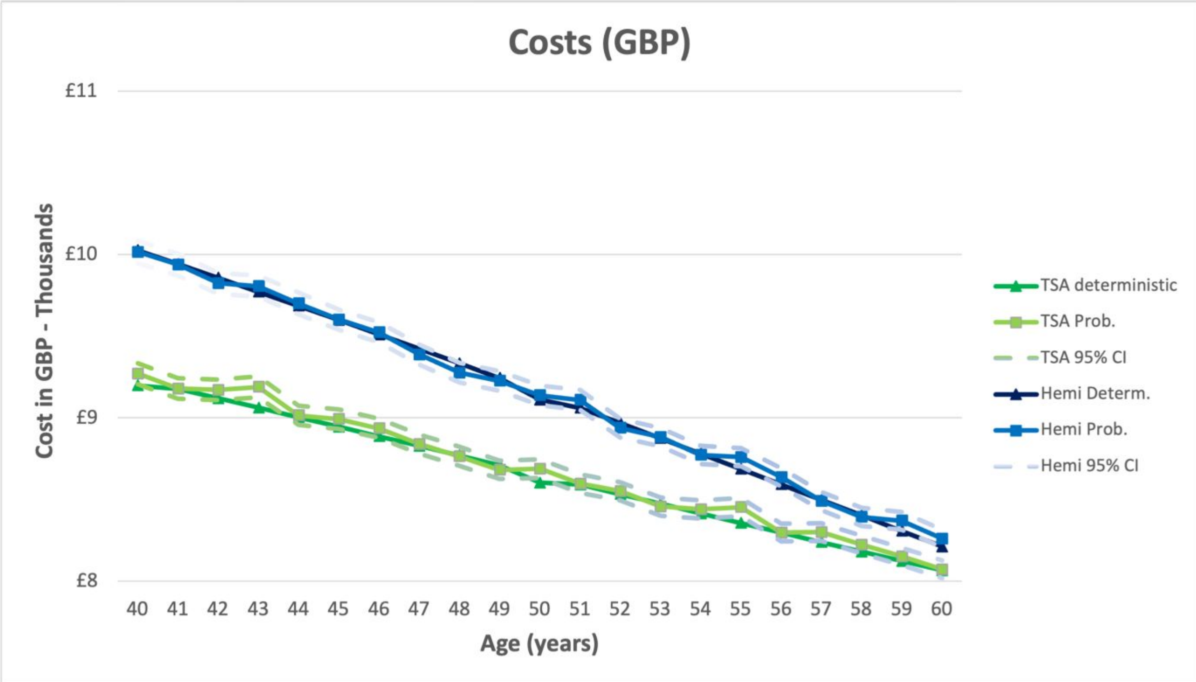

Figure 4. Costs by age for male patients aged 60 years and younger. The same trend was seen in the female cohort.

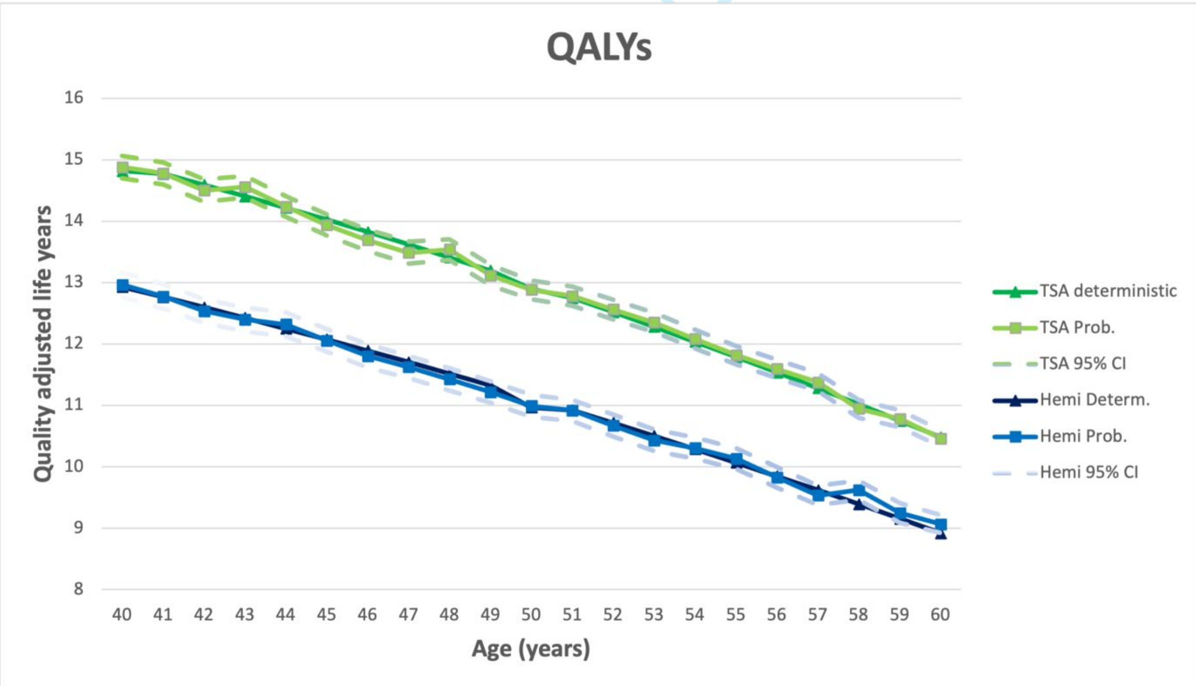

Figure 5. Quality-adjusted life years by age for male patients aged 60 years and younger. The same trend was seen in the female cohort.

CHEERS 2022 Checklist

Topic	No.	Item	Location where item is reported
Title			
	1	Identify the study as an economic evaluation and specify the interventions being compared.	Page 1
Abstract			
	2	Provide a structured summary that highlights context, key methods, results, and alternative analyses.	Pages 2&3
Introduction			
Background and objectives	3	Give the context for the study, the study question, and its practical relevance for decision making in policy or practice.	Pages 4&5
Methods			
Health economic analysis plan	4	Indicate whether a health economic analysis plan was developed and where available.	Submitted to the National Joint Registry
Study population	5	Describe characteristics of the study population (such as age range, demographics, socioeconomic, or clinical characteristics).	Page 6
Setting and location	6	Provide relevant contextual information that may influence findings.	Page 6
Comparators	7	Describe the interventions or strategies being compared and why chosen.	Page 4
Perspective	8	State the perspective(s) adopted by the study and why chosen.	Page 6
Time horizon	9	State the time horizon for the study and why appropriate.	Page 6
Discount rate	10	Report the discount rate(s) and reason chosen.	Page 10
Selection of outcomes	11	Describe what outcomes were used as the measure(s) of benefit(s) and harm(s).	Pages 7-9
Measurement of outcomes	12	Describe how outcomes used to capture benefit(s) and harm(s) were measured.	Pages 7-9
Valuation of outcomes	13	Describe the population and methods used to measure and value outcomes.	Pages 7-11

Topic	No.	Item	Location where item is reported
Measurement and valuation of resources and costs	14	Describe how costs were valued.	Pages 9&10, appendix
Currency, price date, and conversion	15	Report the dates of the estimated resource quantities and unit costs, plus the currency and year of conversion.	Pages 9&10, appendix
Rationale and description of model	16	If modelling is used, describe in detail and why used. Report if the model is publicly available and where it can be accessed.	Pages 6-8, 10&11
Analytics and assumptions	17	Describe any methods for analysing or statistically transforming data, any extrapolation methods, and approaches for validating any model used.	Pages 7-11
Characterising heterogeneity	18	Describe any methods used for estimating how the results of the study vary for subgroups.	Page 11
Characterising distributional effects	19	Describe how impacts are distributed across different individuals or adjustments made to reflect priority populations.	Page 11
Characterising uncertainty	20	Describe methods to characterise any sources of uncertainty in the analysis.	Pages 10&11
Approach to engagement with patients and others affected by the study	21	Describe any approaches to engage patients or service recipients, the general public, communities, or stakeholders (such as clinicians or payers) in the design of the study.	Page 21
Results			
Study parameters	22	Report all analytic inputs (such as values, ranges, references) including uncertainty or distributional assumptions.	Page 14
Summary of main results	23	Report the mean values for the main categories of costs and outcomes of interest and summarise them in the most appropriate overall measure.	Page 12
Effect of uncertainty	24	Describe how uncertainty about analytic judgments, inputs, or projections affect findings. Report the effect of choice of discount rate and time horizon, if applicable.	Pages 12-17
Effect of engagement with patients and others affected by the study	25	Report on any difference patient/service recipient, general public, community, or stakeholder involvement made to the approach or findings of the study	Not reported
Discussion			

Topic	No.	Item	Location where item is reported
Study findings, limitations, generalisability, and current knowledge	26	Report key findings, limitations, ethical or equity considerations not captured, and how these could affect patients, policy, or practice.	Pages 18-20
Other relevant information			
Source of funding	27	Describe how the study was funded and any role of the funder in the identification, design, conduct, and reporting of the analysis	Page 21
Conflicts of interest	28	Report authors conflicts of interest according to journal or International Committee of Medical Journal Editors requirements.	Page 21

From: Husereau D, Drummond M, Augustovski F, et al. Consolidated Health Economic Evaluation Reporting Standards 2022 (CHEERS 2022) Explanation and Elaboration: A Report of the ISPOR CHEERS II Good Practices Task Force. Value Health 2022;25. doi:10.1016/j.jval.2021.10.008

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Cost-effectiveness of total shoulder arthroplasty compared to hemiarthroplasty

A study using data from the National Joint Registry

Abstract

Objectives

The aim of this study was to compare the cost-effectiveness of total shoulder arthroplasty (TSA) and hemiarthroplasty (HA) and explore variation by age and gender.

Design

Cost-effectiveness analysis using a lifetime cohort Markov model.

Setting

National population registry data.

Participants

Model parameters were informed by propensity score matched comparisons of TSA and HA in patients with osteoarthritis and an intact rotator cuff using data from the National Joint Registry.

Interventions

Total shoulder arthroplasty and hemiarthroplasty

Primary outcome measures

Quality adjusted life years (QALYs) and healthcare costs for age and gender subgroups. A probabilistic sensitivity analysis was performed.

Results

In all subgroups TSA was more cost effective, with probability of being cost-effective about 70% for TSA versus 30% for HA at any willingness-to-pay threshold above of £1,100 per QALY. TSA was dominant in young patients (≤ 60 years) with a mean cost saving of £463 in men and £658 in women, and a mean QALY gain of 2 in both men and women. In patients aged 61-75 years there was a mean cost saving following HA of £395 in men and £181 in women, while QALYs remained superior following TSA with a 1.3 gain in men and 1.4 women. In the older cohort (> 75 years) the cost difference was highest and the QALY difference lowest; there was a cost saving following HA of £905 in men and £966 in women. The mean QALY gain remained larger after TSA: 0.7 in men and 0.9 in women.

Conclusion

TSA was more cost effective than HA in patients with osteoarthritis. QALYs were superior following TSA in all patient groups. Cost differences varied by age and TSA was dominant in young patients.

Strengths and limitations

- Data from the National Joint Registry was used to inform estimates of health utility and cost in matched groups of total shoulder arthroplasties and hemiarthroplasties.
- The analysis was separated by age (≤ 60 years, 61-75 years, >75 years) and gender.
- Modelling assumptions were necessary to estimate parameters beyond the 9 years of available follow-up.
- There remains a risk of confounding of the relationship between TSA and HA despite matching on propensity scores.

Introduction

Shoulder arthroplasties are increasingly used in the management of glenohumeral osteoarthritis (OA) and the annual costs are substantial [1,2]. Shoulder arthroplasties can be classified into two groups; anatomical and reverse prostheses. Total shoulder arthroplasty (TSA) and hemiarthroplasty (HA) are anatomical prostheses which are used in patients with an intact rotator cuff. Recent population registry studies showed TSA has a lower rate of revision and re-operation and results in superior Patient Reported Outcome Measures (PROMs) compared to HA [3,4]. The risk of revision arthroplasty has been shown to differ by patient age and gender which may result in cost-effectiveness varying in different groups [5]. TSA implants are more expensive and the duration of surgery is longer, however this initial cost difference may have limited impact over the lifetime of the patient.

The management of glenohumeral osteoarthritis in young patients is an area of particular uncertainty. This group has the highest rate of revision and reoperation across the patient's lifetime and the National Institute of Health and Care Excellence (NICE) recommended an economic analysis of TSA vs HA in patients 60 years and under [6]. Economic analyses from North America compared TSA with HA and showed TSA to be more costs effective to varying degrees [7–9]. The parameters were calculated from observational studies and small randomised trials. The data on which to base the utility assumptions were limited and additional costs of reoperations were not included.

The National Joint Registry (NJR) of England, Wales, Northern Ireland, and the Isle of Man includes a large population of anatomical shoulder replacements, data entry commenced in 2012 [10]. Costs paid for components are collected from hospitals across contributing regions of the United Kingdom to provide a more granular estimate of prosthesis costs. These data provide the opportunity to compare anatomical shoulder arthroplasties within age and gender subgroups. The aim of this study was to determine whether TSA or HA was more cost-effective in the management of glenohumeral osteoarthritis in patients with an intact rotator cuff and explore variation by age and gender.

Method

The Consolidated Health Economic Evaluation Reporting Standards 2022 (CHEERS 2022) reporting guideline was used to inform this report (see Supplemental Material) [11].

Population characteristics

The study population for estimation of the revision and re-operation parameters included 14,698 anatomical shoulder arthroplasties from a prior study using NJR data linked to Hospital Episode Statistics (HES) [4]. Data were collected from April 2012 until July 2021**.** Arthroplasties performed for an indication other than OA or in patients without an intact rotator cuff were excluded. The mean age of the population was 70.1 (SD 9.6), 31.7% male 68.3% female. The majority had an ASA of II or III (ASA I - 9.0%, II - 67.5%, III - 23.0%, IV - 0.4%). 15.2% were in the most deprived socioeconomic quartile, compared to 29.4% in the least deprived quartile as defined in HES [12]. The population flow diagram is shown in Supplemental Figure 1. The number of arthroplasties in each group and full population characteristics by implant are shown in Supplemental Tables 2-5.

Model structure and perspective

Cost-effectiveness analysis was undertaken for hospital costs with a maximum time horizon of 60 years. The time horizon varied according to the gender and age-specific mortality rate of UK life tables. The age for the cohort entering the model varied from 40 to 90 years. A Markov model with time-dependency was used, the structure of the model is shown in figure 1. The model simulated a 1,000-patient cohort separately for each age and gender. Patients transitioned through a 6-state model according to specified transition probabilities representing time-dependent risks for annual cycles (Supplemental Tables 6 – 11). The model structure separated subgroup heterogeneity from parametric uncertainty using subgroups defined by age group and gender as previously described [13,14].

Figure 1. Model structure. RR1 - revision rate, RR2 - re-operation rate, MR - mortality rate, RRR - re-revision rate, MR - mortality rate.

Patients started with a primary TSA or HA and after a 1 year cycle, moved to one of four different heath states (2) to (5): state (2) remain in the ‘successful primary’; state (3) ’revision’ of their primary arthroplasty; state (4) ‘reoperation’; or reached the final state (6). In the next year cycle, a new health state (5) ‘re-revision’ was added to capture patients requiring a second revision procedure. The rest of the cohort evolved across states (2) to (4), and (6) according to the transition probabilities. Cycles were repeated until all patients had died within the 60-year time horizon.

Outcomes – revision, re-operation, and mortality

The rates of revision and re-operation for HA and TSA were estimated using patient-level data from the NJR. The rates were calculated separately for each of three age groups (i) 60 years or younger, (ii) 61-75 years, and (iii) over 75 years. HA and TSA were matched using propensity scores within each age group to minimise baseline differences in population characteristics using 11 covariates reported previously [4]. These included age, sex, American Society of Anesthesiologists Physical Status Classification System (ASA), rotator cuff condition, primary surgeon seniority, assistant seniority, surgical approach, unit type, mean number of anatomical shoulder arthroplasties performed per year by the responsible consultant, Charlson Comorbidity Index, and deprivation index. The standard mean difference (SMD) were less than 0.1 for each of the 11 co-variates. Characteristics of the subgroup populations and details of the matching process are available in Supplemental Tables 3 - 5.

Follow-up data was available for 9 years and modelling was necessary to extrapolate beyond the available follow-up period. Parametric survival models were specified separately to model the implant duration as time-to-event from primary surgery to revision and reoperation for each implant and subgroup, using the Weibull distribution which allows for increasing or decreasing hazards over time, and it has shown good adjustment to estimate time-to-event clinical outcomes for orthopaedic implants [15]. The transition probabilities for each cycle, t*p(cycle t),* were calculated using the cumulative hazards, *H(t),* according to the methods described below:

$$tp(cycle\ t) = 1 - exp\{H(t-1) - H(t)\}$$

The cumulative hazard for the Weibull distribution is $H(t) = \lambda t^{\kappa}$, and the parameters λ (scale) and κ (shape) were estimated for each subgroup. A Weibull regression was used to estimate the hazards so that the distribution of time-to-event, T, was a function of gender, age, and the whether the prothesis was HA. The hazard function of a Weibull regression was modelled as follows:

$$lnh(t) = \ lnh0(t) + \beta_0 + \beta_1 age + \beta_1 male + \beta_3 hemiarthroplasty$$

$lnh(t)$ represents the baseline log hazard at time point t, with $h0(t) = \lambda\kappa t^{\kappa-1}$. The effect of HA is measured as a multiplicative effect (additive in the log scale) with the estimated coefficient β_3, so that the risk of revision or reoperation is larger for HA than for TSA if $\beta_3 > 0$, with the multiplicative effect measured by $\exp(\beta_3)$.

The rate of re-revision following a successful revision was taken from a meta-analysis [16]. The transition to death was considered as all-cause mortality, measured from the most recent 2018-20 UK life tables, as no deaths were observed during surgery [4]. The life tables present the mortality rate for each age separately for men and women. The mortality rate from age 40 to 100 were used as the transition probabilities to death for each age within each one of the three age groups.

Outcomes – health related quality of life

Oxford shoulder scores (OSSs) from a previous population-level comparative study were used to estimate health-related quality of life (HRQoL) [3,17]. The results were skewed towards the highest score and the median score was used for the purpose of the quality of life estimations [3]. The OSSs were mapped to the EQ-5D-5L [17]. There was minimal change in the OSS from 6 months to 5 years [3]. The model addressed the postoperative recovery period in year 1 by halving the improvement in the EQ-5D-5L value from baseline for the first 6 months followed by the full EQ-5D-5L for the second 6 months. There was no further change in HRQoL after 1 year.

Reports of shoulder scores in revision arthroplasty are very limited [16]. Revision utilities were estimated as 15% less than the combined TSA and HA EQ-5D values. This estimate was made from a combination of data in shoulder and knee arthroplasty [14,16] The same trajectory of improvement in HRQoL in the first year was applied to the revised state. HRQoL following re-revision was assumed to fall by the same proportion as it did from primary to revision arthroplasty. Full details of HRQoL estimations are included in Supplemental Table 1.

Cost estimates

The primary source of information for cost estimation were hospital reimbursement values for shoulder procedures from the 2022/2023 National Tariff Payment System using Healthcare Recourse Group (HRG) codes [18]. The codes do not differentiate between the two types of anatomical shoulder arthroplasty. Two key elements of the total cost of each procedure were used to estimate the difference between primary HA and TSA: length of the procedure and component costs. Costs are described in the British Pound (GBP). Data from the NJR EMBED price benchmarking service was used to calculate the mean price of TSA and HA components [19]. The HRG code HN52 "Very Major Shoulder Procedures for Non-Trauma" was used as the baseline cost for HA and TSA [18]. Theatre time costs were calculated using estimated durations of surgery combined with theatre time cost estimations, the full calculation is available in the Supplemental Figure 3 [20,21]. The total difference in cost was halved and added to the HRG value to estimate the TSA cost and subtracted from the HRG value to estimate HA cost. This meant the mean cost of HA and TSA was equal to the NH52 code value. See Supplemental Tables 14 for further information and the individual values.

The cost of a revision and re-revision arthroplasty was estimated from relevant HRG codes and assumed to be equal between the groups. The model did not include community costs which are minimal compared with the overall cost [14]. A discount rate of 3.5% was applied for costs and health outcomes as recommended by NICE [22].

Parameter distributions for the probabilistic sensitivity analysis

Estimation by subgroups separated demographic heterogeneity from parameter uncertainty, the latter was modelled as a probabilistic sensitivity analysis (PSA). The probability distributions used for the input parameters were informed by the sample means and variability. For the parameters of the Weibull survival models the distributions were multivariate log-normal. To estimate random values from the survival models the raw coefficients (β_0, β_1, β_2, β_3, κ) were assumed to follow a multivariate normal distribution with a correlation structure given by the coefficients from the correlation matrix. Cholesky decomposition of the covariance matrix was performed to simulate the correlated random variates [13]. The parameters of the re-revision rate were assumed to follow a beta distribution. The beta distribution was also used to introduce uncertainty in health utilities on the assumption that no value was less than 0, as observed in the data. The gamma distribution was used to model cost uncertainty due to its favourable properties in this context as a positive and skewed distribution [13].

Final analyses

The model outcomes were estimated separately by gender and age for each of the three age groups: (i) 60 years or younger, (ii) 61-75 years, and (iii) over 75 years. Mean Quality Adjusted Life Year (QALYs) and costs were calculated for TSA and HA and were presented as incremental cost-effectiveness ratios (ICERs). Monte Carlo simulations were used to address parametric uncertainty by generating 1,000 random draws of the assumed statistical distributions for the input parameters. For each one of the three patient subgroups, for a given age and gender, the differential mean costs and QALYs between TSA and HA were calculated. The initial assessment compared these means and established whether one implant dominates the other (if it is less costly and generates more QALYs) or whether it is cost-effective, with incremental costs and incremental QALYs, if the ICER is below the NICE cost-effectiveness threshold established between £20,000-£30,000 per QALY. The probability of either TSA or HA being cost effective was calculated for a range of cost-effectiveness thresholds and the cost-effectiveness acceptability curves (CEAC) were drawn for each patient subgroup. The analyses used to generate the parameter estimates were performed using StataSE v 16 (StataCorp LLC, College Station, TX). The cost effectiveness model was constructed in EXCEL Version 16.80 (Microsoft Corporation, Redmond, Washington). The Markov models were simulated in Excel.

Patient and public involvement

Patients were involved in the design of the wider body of work comparing total shoulder arthroplasty and hemiarthroplasty [3,4]. The Patient and Public Involvement group at our institution met prior to commencement of the study. This included four surgeons and 32 pre-operative and post-operative arthroplasty patients. Further individual discussions were carried out with pre-operative shoulder arthroplasty patients.

Results

Input parameter values

HA increased the rate of revision and re-operation for the three age groups, more strongly for revision in younger patients than for over 75-year-olds. The estimated mean EQ-5D-5L utility was higher following primary TSA compared to primary HA (Supplemental Table 1). The mean cost of a primary TSA was £6576 compared to £5456 following HA (Supplemental Table 14). Other input parameters were taken from the National Tariff Payment System and the literature. The full tables of input parameters are included in Supplemental Tables 12-14.

Main findings

TSA dominated HA in the young cohort, with TSA resulting in mean cost savings of £463 and a 2.0 QALY gain in men, and a saving of £658 and 2.0 QALY gain in women entering the model at age 50 and representing patients aged 60 years and younger (table 1). The cost savings reversed for the older cohort entering at age 80, representing patients over 75, with HA around £966 less costly than TSA in women, and £905 less costly in men but with 0.9 QALYs less than TSA in women and 0.7 in men. For the middle cohort entering the model at age 67 and representing ages 61-75, there was a cost saving following HA in men and women. TSA resulted in a QALY gain of 1.3 for men and 1.4 for women**.** The probability of TSA being more cost-effective than HA was constant at around 70% for all willingness-to-pay thresholds considered in decision-making in the UK (£20,000 to £30,000 per QALY). The cost-effectiveness planes for each age group in females and males are shown in figures 2 and 3. The results of the cost-effectiveness analyses are presented for each age cohort. Gender subgroup heterogeneity was indistinguishable from parametric uncertainty in the cost-effectiveness (CE) plane therefore the cost-effectiveness acceptability curves (CEAC) are presented for women only (figure 4). The CEAC for men is available in Supplemental Figure 2.

Figure 2. Cost-effectiveness plane: Female 50 – Green, female 67 – Blue, female 80 – Orange. QALYS – Quality Adjusted Life Years.

Figure 3. Cost-effectiveness plane: Male 50 – Green, male 67 – Blue, male 80 – Orange. QALYS –

Quality Adjusted Life Years.

	TSA Mean		**HA** Mean		**Difference (HA – TSA)**		**ICER**	
	Cost (£) (95% CI)	QALYs (95% CI)	Cost (£) (95% CI)	QALYs (95% CI)	Costs (£) (95% CI)	QALYs (95% CI)	Cost per QALY (£)	(Prob. TSA cost effective)
Female ≤ 60	9,223 (9,160, 9,287)	13.63 (13.5,13.8)	9,882 (9,817, 9,946)	11.64 (11.5,11.8)	658 (581,735)	-1.99 (-2.2,-1.8)	TSA dominant -331	69%
Male ≤ 60	8,610 (8,553, 8,666)	13.01 (12.9, 13.2)	9,073 (9,012, 9,133)	11.00 (10.8,11.2)	463 (387,538)	-2.01 (-2.3,-1.8)	TSA dominant -230	71%
Female 61-75	7,548 (7,493, 7,602)	9.30 (9.2,9.4)	7,367 (7,316, 7,418)	7.85 (7.7,8.0)	-181 (-253,-109)	-1.44 (-1.6,-1.26)	126	69%
Male 61-75	7,291 (7,238, 7,344)	8.51 (8.4,8.6)	6,895 (6,846, 6,945)	7.25 (7.1,7.4)	-395 (-466,-325)	-1.26 (-1.4,-1.1)	314	68%
Female > 75	6,861 (6,808, 6,914)	5.26 (5.2,5.3)	5,895 (5,848, 5,943)	4.32 (4.2,4.4)	-966 (-1,038, - 893)	-0.94 (-1.1,-0.8)	1,024	70%
Male > 75	6,807 (6,754, 6,859)	4.60 (4.5,4.7)	5,902 (5,854, 5,950)	3.87 (3.8,3.9)	-905 (-976,- 833)	-0.73 (-0.8,-0.6)	1,236	68%

Notes:
The 95% CI is estimated using the standard error of the mean is SEM=SD/$\sqrt{1000}$, where SD is the sample standard deviation of the 1,000 random draws in the PSA.

Table 1. Costs, quality adjusted life years (QALYs), and cost-effectiveness for age and gender subgroups.

Young cohort ≤ 60 years

The slightly smaller costs and QALYs for men compared to women were consistent with lower hazard ratios for revision and re-operation in men along with a shorter lifespan: men accumulate less costs and QALYs during the predicted time horizon. The mean ICERs for women and men aged 50 were negative in the North-West area of the CE plane, with incremental costs and decremental QALYs, therefore TSA was dominant. The rates of revision and re-operation were estimated separately for each age within the cohort. There was a decrease in costs and QALYs as age increased (Supplemental Figures 4 and 5). The difference in costs between TSA and HA decreased with age reflecting the progressive shortening of life span. In contrast, the difference in QALYs remained similar by age.

The CEACs shown in figure 4 imply that TSA had a higher probability of being cost-saving that HA, even at the willingness-to-pay threshold of £0 (indicating cost-savings), due to the larger hazards of revisions and reoperations for HA than TSA whose costs offset the difference in initial cost. The QALY gain reinforces the probability of TSA being dominant over TA.

Middle cohort 61 – 75 years

The overall costs for HA were lower than TSA. The cost of TSA was slightly higher following HA in males and females. TSA rendered more QALYs than HA in both males and females, therefore the ICER was positive but on the South-West quadrant of the CE plane. This quadrant is used for disinvestment decisions (withholding the replacement) if the savings are large – at least more than £20,000-£30,000 according to NICE threshold – which was not this case. To show that HA was not cost effective, the net monetary benefit (NMB) was calculated for females, and it was negative, which showed HA was not cost-effective:

$$NMB = Threshold * \Delta QALY - \Delta Cost = £20{,}000 * (-1.44) - (-181) = -28{,}619$$

At the willingness-to-pay threshold of £0, there was cross-over; both HA and TSA had the same probability of being cost saving. The hazards of revision and re-operation were still larger for HA than TSA, however the middle cohort accumulated less years of costs.

Older cohort over 75 years

The older cohort accumulated the fewest years of costs and QALYs. The hazards of revision and re-operation remained larger for HA than TSA but the greatest cost saving following HA was shown in this cohort. For both female and male aged 80, HA was less costly than TSA because the HA prosthesis is cheaper and the incremental costs from more reoperations and revisions were negligible. However, the savings did not justify a disinvestment in TSA or replacing TSA by HA. Differential QALYs favour TSA, and the NMB was negative (NMB= 20,000*(-0.94)-(-966) =-17,834).

At the willingness-to-pay threshold of £0, HA was more likely to be cost saving. At a threshold of £1100 – £1250 per QALY, there was cross-over in the probability of HA and TSA being cost-effective, and TSA is more cost-effective, with probability up to 68% for men for a threshold over £1250 per QALY.

Figure 4. Cost-effectiveness acceptability curves in women.

Discussion

Principal findings

The results showed cost effectiveness was likely to be higher following TSA for all age subgroups at a threshold of £20,000-£30,000 per QALY. QALYs were higher for TSA in all age groups. In the young cohort costs were higher following HA. Despite the lower costs of HA implants and shorter theatre time, this was offset by the additional costs of revision/re-operation. In the older cohort TSA was more expensive than HA because the higher initial costs were not offset by the lower overall rate of revision and reoperation after TSA during patients' shorter lifetime. The sensitivity analyses accounted for the uncertainty in the estimates and within each age group the probability of cost-effectiveness was approximately 0.7 for TSA at current NICE threshold of £20,000-£30,000 per QALY. There is particular interest in the cost-effectiveness of anatomical shoulder replacements in young patients [6]. TSA was dominant in patients 60 years and younger at a willingness to pay threshold of £0, primarily due to the large difference in revision rate and longer lifetime of patients in this subgroup, implying TSA is cost saving compared to HA. Postoperative shoulder function may determine whether patients can return to work [23]. As the number of shoulder arthroplasties performed each year increases, including in young patients, the loss of productivity due to the additional time required off work should be considered. This further supports the economic arguments for TSA given the superior post-operative shoulder function.

Strengths and limitations

This is the first study to investigate cost-effectiveness in anatomical shoulder replacements using parameter estimates based on National registry data from the U.K., and the first to investigate cost-effectiveness in young patients. Age is an important driver of revision rate, and the analysis was split into 3 age subgroups to better represent subgroup differences in cost-effectiveness across the population. Confounding by indication remained a concern and arthroplasties within each age group

were matched on propensity scores calculated from 11 important variables to minimise the risk of baseline differences between the groups. The study was limited to patients with osteoarthritis and an intact rotator cuff. Revision and re-operation estimates were based on models extrapolated from registry data with a maximum follow-up of 9 years. The sensitivity analysis demonstrated uncertainty in the results. The largest uncertainty was in the utility and cost estimates. The uncertainty in implant survival was smaller.

Modelling assumptions were necessary. Individuals could not undergo revision or re-operation within the first year following the primary procedure, and revision and re-operation could not occur within the same year. We assumed there was no change in utility after the first 6 months, and the annual utility was averaged accordingly. The OSS may continue to improve beyond 6 months after TSA, and the ceiling affect shown in the OSS at 5 years may result in an underestimate of the improvement. The same trajectory of utility following revision surgery was assumed. The utility estimates required transformation of the OSS to the EQ5D. Despite a mapping algorithm based on high quality data, this introduced additional uncertainty. Revision utilities were estimated by reducing the combined primary utility by 15%. In a prior systematic review shoulder scores were collected following revision arthroplasty but only one small study of 15 patients reported OSSs following TSA and none following HA [16]. No mapping studies are available to estimate the EQ5D from other shoulder scores.

The cost estimates centred around hospital reimbursement values to improve the generalisability of the results. The cost of theatre time will vary by unit, a range of values are reported, and there is uncertainty among hospital managers [24]. The value selected for this work was taken from pooled data from NHS Scotland [21]. A median value of implant costs nationally was used to ensure they were generalisable compared to the alternative of relying on procurement costs of a limited number of implants from a single, or small number of hospitals. A single reimbursement code was used for each of the re-operation and revision procedures representing patients with moderate co-morbidities. The standard deviation of the cost estimates for re-operation and revision were assumed to be 10% of the cost of the procedure. Post-operative mortality was assumed to be equivalent to age and gender specific mortality recorded nationally, no evidence could be found to contradict this assumption. Previous work showed there was no difference between the implants at 1 year [4]. The national life tables were considered a more accurate predictor of death than summary estimates generated from a relatively small population for this rare outcome. If the rate of death was higher following surgery than in the general population, this may overestimate the cost-effectiveness of both implants.

Comparison to other studies

Prior work comparing the cost-effectiveness of HA and TSA, is from North America [7–9]. The most recent study by Lapner et al showed TSA was more cost-effective [7]. The results were more strongly in favour of TSA than in this study, which may be a product of the difference in North American costs compared to U.K. costs, and the revision and utility estimates. The utility assumptions for HA were based on patients following proximal humerus fractures which may underestimate the effect of HA [7]. The earlier studies used more limited datasets and showed superiority of TSA to varying degrees [8,9]. Given the sensitivity of the models to revision rate shown in this study, the quality of the data used to estimate implant survival is particularly important.

The use of HA has declined however it continues to be used, most commonly in younger patients, where there is particular uncertainty about the most appropriate implant [6]. Multiple factors are considered when selecting implants for a patient. Prior work has demonstrated a higher revision rate following HA and inferior shoulder scores [3,4]. This study showed TSA was cost effective in the management of glenohumeral osteoarthritis, and the superiority of TSA was most clear in the younger cohort, further supporting the use of TSA in patients with osteoarthritis and an intact rotator cuff.

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Ethical approval

The study used pseudo-anonymised data from a national clinical registry. The Health Research Authority guidance confirmed ethical approval was not required.

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Competing interests

PR receives funding for alternative work from Mathys and Orthopaedic Research UK. AR receives funding for alternative work from the NIHR, AO UK&I and DePuy J&J Ltd. AR is a member of the NIHR i4i funding committee. AD, BZ, SS, AL, and MVB have no competing interests.

Data sharing arrangement

Original data can be requested from the National Joint Registry

Author contributions

Andrew Davies is the guarantor

AD	Conceptualisation, methodology, analysis, writing – original draft.
BZ	Data curation, methodology, analysis, writing – original draft
SS	Conceptualisation, analysis, writing – review and editing
AL	Methodology, analysis, supervision, writing – review and editing
MVB	Methodology, analysis, writing – review and editing
AR	Conceptualisation, supervision, writing – review and editing
PR	Conceptualisation, supervision, writing – review and editing

Figure 1. Model structure. RR1 - revision rate, RR2 - re-operation rate, MR - mortality rate, RRR - re-revision rate, MR - mortality rate.

Figure 2. Cost-effectiveness plane: Female 50 – Green, female 67 – Blue, female 80 – Orange. QALYS – Quality Adjusted Life Years.

Figure 3. Cost-effectiveness plane: Male 50 – Green, male 67 – Blue, male 80 – Orange. QALYS – Quality Adjusted Life Years.

Figure 4. Cost-effectiveness acceptability curve in women.

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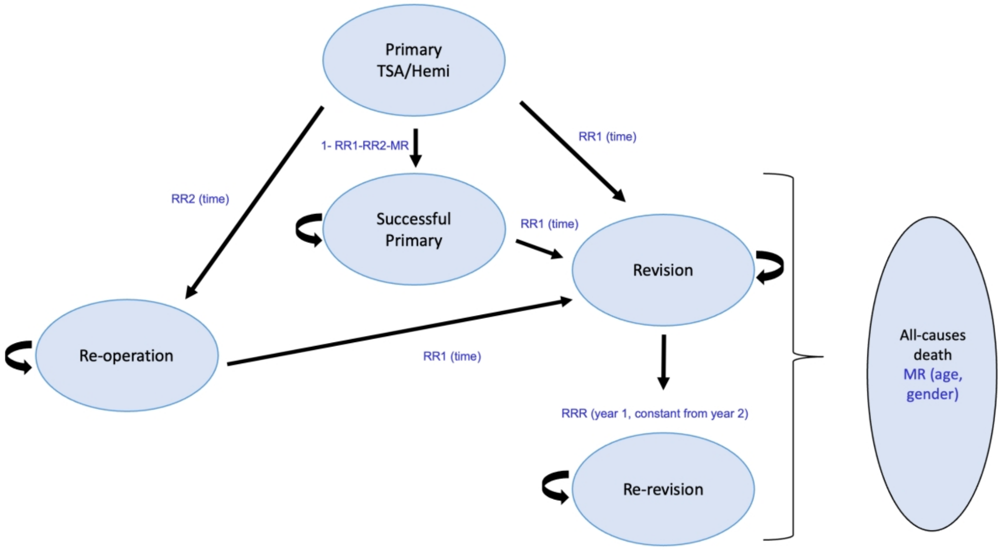

Figure 1. Model structure. RR1 - revision rate, RR2 - re-operation rate, MR - mortality rate, RRR - re-revision rate, MR - mortality rate.

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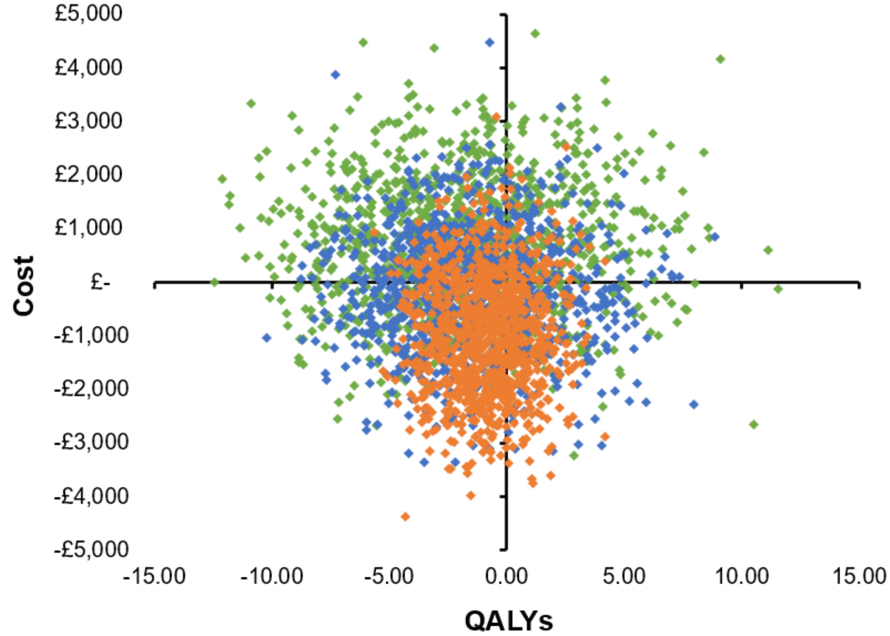

Figure 2. Cost-effectiveness plane: Female 50 – Green, female 67 – Blue, female 80 – Orange. QALYS – Quality Adjusted Life Years.

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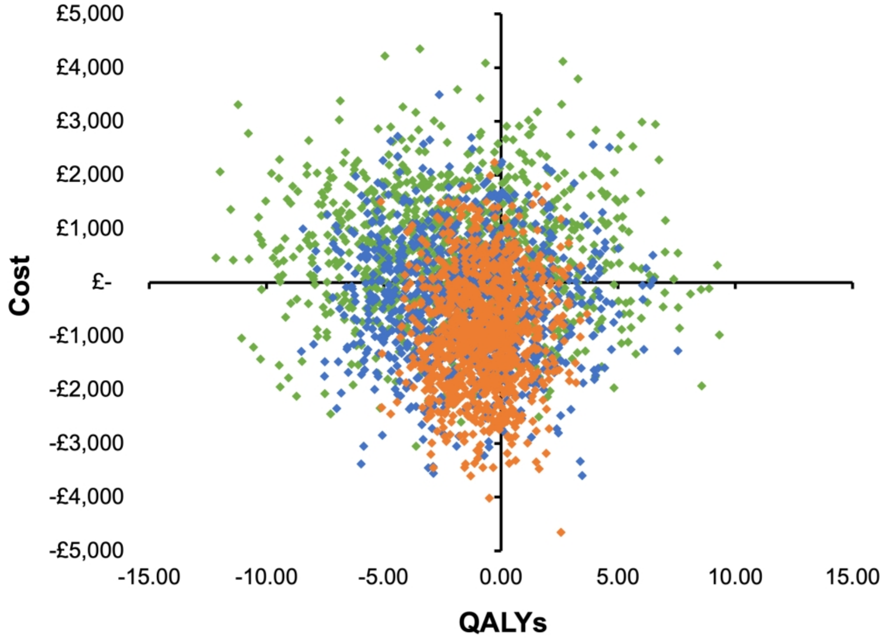

Figure 3. Cost-effectiveness plane: Male 50 – Green, male 67 – Blue, male 80 – Orange. QALYS – Quality Adjusted Life Years.

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Figure 4. Cost-effectiveness acceptability curve in women.

Appendix

Model parameters – health utility

Prosthesis	Procedure	EQ-5D-5L	Standard deviation
TSA	Pre-operative	0.34	
	Success Primary	0.76	0.18
	Success Revision	0.61	0.18
	Recovery Primary	0.66	0.18
	Recovery Revision	0.54	0.18
	Re-revision	0.54	0.18
	Pre-operative	0.34	0.18
Hemi	Pre-operative	0.35	
	Success Primary	0.64	0.22
	Success Revision	0.61	0.22
	Recovery Primary	0.58	0.22
	Recovery Revision	0.54	0.22
	Re-revision	0.54	0.18
	Pre-operative	0.35	0.18

Table 1. EQ-5D-5L utility scores.

Number of shoulders arthroplasties in each age group

Age group	Pre-matching		Post-matching	
	TSA	HA	TSA	HA
≤ 60 years	1471	746	1177	623
61 – 75 years	6002	2010	3714	1889
> 75 years	3008	1461	2323	1236

Table 2. Number of shoulder arthroplasties in each age group.

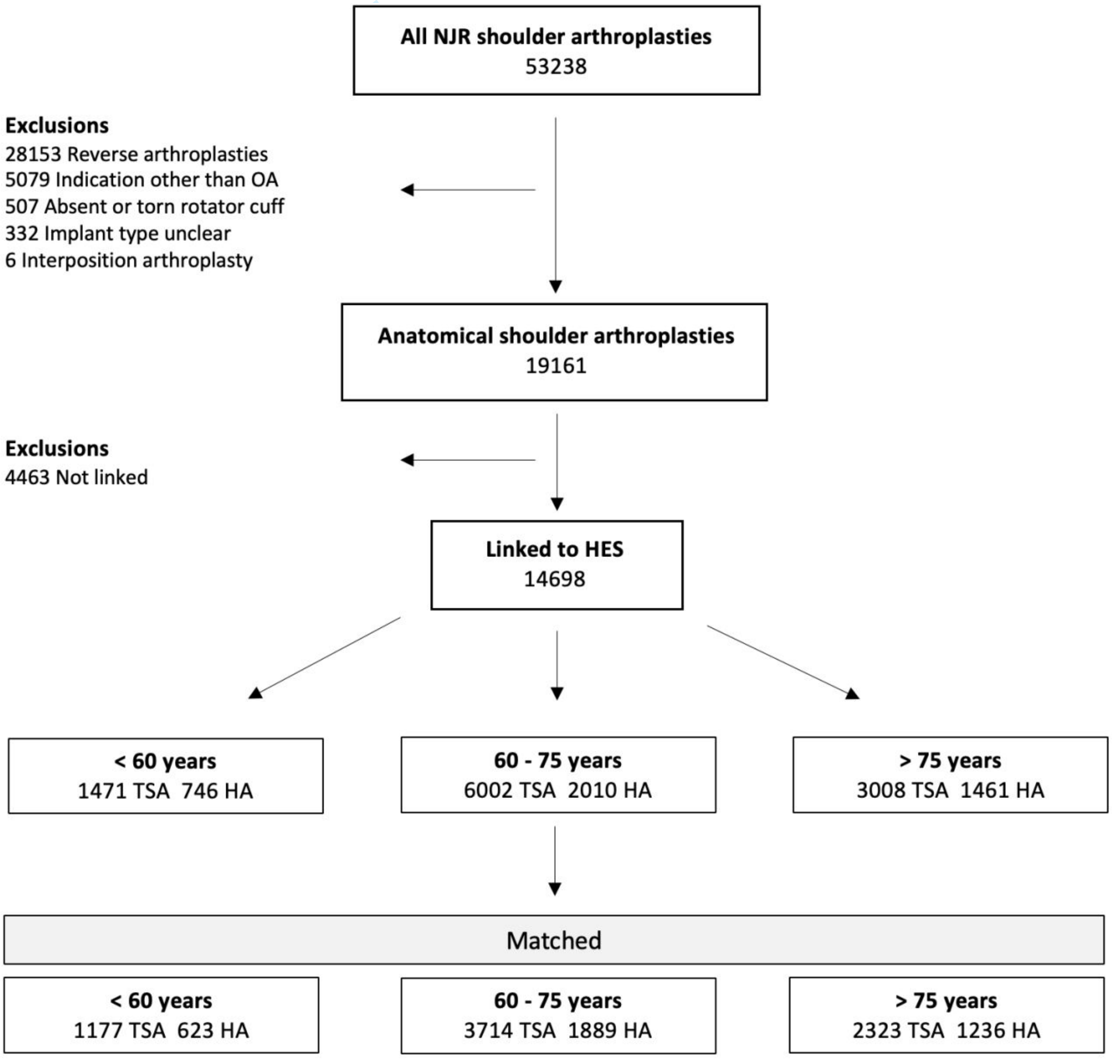

Figure 1. Study flow diagram. Adapted with consent from Davies et al (1).

Matching process

Components of the matching process were varied to achieve the optimal match as defined by the lowest standardised mean difference (SMD) between each variable pre- and post-matching. The lowest SMDs were achieved when patients were matched on the linear predictor (log odds of the propensity score) using a ratio of 1 HA to 2 TSA, greedy matching without replacement and a calliper width of 0.2.

Characteristics pre and post matching – subgroup aged 60 years or less

	Pre-matching			Post-matching		
Characteristic	TSA	HA	SMD	TSA	HA	SMD
Age (mean, SD)	54.5 (5.4)	52.0 (7.4)	0.382	53.8 (5.7)	53.6 (5.7)	0.042
Gender (number, %)						
Male	767 (52.1)	481 (64.5)	0.252	681 (57.9)	382 (61.3)	0.071
Female	704 (47.9)	265 (35.5)		496 (42.1)	241 (38.7)	
ASA (number, %)						
I	283 (19.2)	203 (27.2)	0.197	248 (21.1)	144 (23.1)	0.054
II	950 (64.6)	422 (56.6)		724 (61.5)	377 (60.5)	
III	230 (15.6)	118 (15.8)		200 (17.0)	99 (15.9)	
IV	8 (0.5)	3 (0.4)		5 (0.4)	3 (0.5)	
Rotator cuff (number, %)						
Attenuated/normal	1460 (99.3)	730 (97.9)	0.117	1166 (99.1)	617 (99.0)	0.003
Repaired	11 (0.7)	16 (2.1)		11 (0.9)	6 (1.0)	
Operating surgeon (number, %)						
Consultant	1369 (93.1)	704 (94.4)	0.168	1117 (94.9)	593 (95.2)	0.016
SpR/ST3-ST8	46 (3.1)	30 (4.0)		39 (3.3)	20 (3.2)	
Speciality doctor	31 (2.1)	4 (0.5)		8 (0.7)	4 (0.6)	
F1-ST2	0 (0.0)	1 (0.1)		0 (0.0)	0 (0.0)	
Other	25 (1.7)	7 (0.9)		13 (1.1)	6 (1.0)	
Surgical assistant (number, %)						
Consultant	121 (8.2)	59 (7.9)	0.012	95 (8.1)	45 (7.2)	0.032
Other	1350 (91.8)	687 (92.1)		1082 (91.9)	578 (92.8)	
Surgical approach (number, %)						
Deltopectoral	1369 (93.1)	704 (94.4)	0.213	1096 (93.1)	573 (92.0)	0.071
Deltoid detachment	4 (0.3)	1 (0.1)		1 (0.1)	1 (0.2)	
Other	2 (0.1)	0 (0.0)		0 (0.0)	0 (0.0)	
Posterior	3 (0.2)	2 (0.3)		3 (0.3)	2 (0.3)	
Superior (Mackenzie)	69 (4.7)	63 (8.4)		66 (5.6)	40 (6.4)	
Trans-deltoid	24 (1.6)	13 (1.7)		11 (0.9)	7 (1.1)	
Unit type (number, %)						
NHS	1440 (97.9)	735 (98.5)	0.048	1159 (98.5)	613 (98.4)	0.006
Independent	31 (2.1)	11 (1.5)		18 (1.5)	10 (1.6)	
Cases / yr (mean, SD)	9.3 (5.5)	8.2 (4.9)	0.198	8.5 (5.0)	8.4 (5.0)	0.033
Charlson Comorbidity Index(mean, SD)	0.8 (1.3)	0.8 (1.3)	0.006	0.8 (1.3)	0.8 (1.3)	0.025
Deprivation level (number, %)						
Least deprived	314 (21.6)	180 (24.3)	0.080	268 (22.8)	149 (23.9)	0.032
Less deprived	401 (27.6)	185 (25.0)		314 (26.7)	160 (25.7)	
More deprived	391 (26.9)	205 (27.7)		323 (27.4)	172 (27.6)	
Most deprived	349 (24.0)	170 (23.0)		272 (23.1)	142 (22.8)	

Table 3. Characteristics pre- and post-matching, patients age 60 years or less.

Characteristics pre and post matching – subgroup aged 61-75 years

	Pre-matching			Post-matching		
Characteristic	TSA	HA	SMD	TSA	HA	SMD
Age (mean, SD)	69.0 (4.0)	69.0 (4.1)	0.003	69.0 (4.1)	68.9 (4.1)	0.013
Gender (number, %)						
Male	1913 (31.9)	692 (34.4)	0.054	1262 (34.0)	652 (34.5)	0.011
Female	4089 (68.1)	1318 (65.6)		2452 (66.0)	1237 (65.5)	
ASA (number, %)						
I	480 (8.0)	170 (8.5)	0.077	313 (8.4)	157 (8.3)	0.019
II	4252 (70.8)	1369 (68.1)		2526 (68.0)	1290 (68.3)	
III	1259 (21.0)	461 (22.9)		865 (23.3)	435 (23.0)	
IV	11 (0.2)	10 (0.5)		10 (0.3)	7 (0.4)	
Rotator cuff (number, %)						
Attenuated/normal	5945 (99.1)	1961 (97.6)	0.116	3660 (98.5)	1865 (98.7)	0.016
Repaired	57 (1.5)	49 (2.4)		54 (1.5)	24 (1.3)	
Operating surgeon (number, %)						
Consultant	5465 (91.1)	1838 (91.4)	0.077	3404 (91.7)	1735 (91.8)	0.009
SpR/ST3-ST8	120 (2.0)	23 (1.1)		205 (5.5)	101 (5.3)	
Speciality doctor	289 (4.8)	111 (5.5)		60 (1.6)	31 (1.6)	
Other	128 (2.1)	38 (1.9)		45 (1.2)	22 (1.2)	
Surgical assistant (number, %)						
Consultant	540 (9.0)	192 (9.6)	0.019	377 (9.1)	177 (9.4)	0.010
Other	5462 (91.0)	1818 (90.4)		3377 (90.9)	1712 (90.6)	
Surgical approach (number, %)						
Deltopectoral	5569 (92.8)	1771 (88.1)	0.189	3379 (91.0)	1733 (91.7)	0.045
Deltoid detachment	9 (0.1)	3 (0.1)		7 (0.2)	3 (0.2)	
Other	12 (0.2)	4 (0.2)		7 (0.2)	4 (0.2)	
Posterior	10 (0.2)	6 (0.3)		8 (0.2)	5 (0.3)	
Superior (Mackenzie)	283 (4.7)	180 (9.0)		246 (6.6)	108 (5.7)	
Trans-deltoid	119 (2.0)	46 (2.3)		67 (1.8)	36 (1.9)	
Unit type (number, %)						
NHS	5901 (98.3)	1985 (98.8)	0.037	3669 (98.8)	1864 (98.7)	0.010
Independent	101 (1.7)	25 (1.2)		45 (1.2)	25 (1.3)	
Cases / yr (mean, SD)	9.8 (5.6)	8.2 (5.3)	0.304	8.5 (5.1)	8.2 (5.1)	0.060
Charlson Comorbidity Index(mean, SD)	1.1 (1.6)	1.1 (1.5)	0.001	1.1 (1.5)	1.1 (1.5)	0.009
Deprivation level (number, %)						
Least deprived	1655 (28.0)	611 (30.5)	0.073	1114 (30.0)	581 (30.8)	0.022
Less deprived	1945 (32.9)	598 (29.9)		1096 (29.5)	560 (29.6)	
More deprived	1417 (24.0)	483 (24.1)		917 (24.7)	451 (23.9)	
Most deprived	887 (15.0)	311 (15.5)		587 (15.8)	297 (15.7)	

Table 4. Characteristics pre- and post-matching, patients age 61-75 years.

Characteristics pre and post matching – subgroup aged > 75 years

	Pre-matching			Post-matching		
Characteristic	TSA	HA	SMD	TSA	HA	SMD
Age (mean, SD)	80.1 (3.5)	80.9 (3.9)	0.221	80.4 (3.6)	80.4 (3.6)	0.016
Gender (number, %)						
Male	584 (19.4)	236 (16.2)	0.085	410 (17.6)	220 (17.8)	0.004
Female	2424 (80.6)	1225 (83.8)		1913 (82.4)	1016 (82.2)	
ASA (number, %)						
I	120 (4.0)	70 (4.8)	0.092	103 (4.4)	57 (4.6)	0.019
II	2013 (66.9)	914 (62.6)		1492 (64.2)	797 (64.5)	
III	854 (28.4)	466 (31.9)		712 (30.7)	372 (30.1)	
IV	21 (0.7)	11 (0.8)		16 (0.7)	10 (0.8)	
Rotator cuff (number, %)						
Attenuated/normal	2966 (98.6)	1429 (97.8)	0.060	2284 (98.3)	1216 (98.4)	0.005
Repaired	42 (1.4)	32 (2.2)		39 (1.7)	20 (1.6)	
Operating surgeon (number, %)						
Consultant	2666 (88.6)	1308 (89.5)	0.163	2076 (89.4)	1118 (90.5)	0.069
SpR/ST3-ST8	71 (2.4)	11 (0.8)		133 (5.7)	74 (6.0)	
Speciality doctor	154 (5.1)	102 (7.0)		82 (3.5)	33 (2.7)	
Other	117 (3.9)	40 (2.7)		32 (1.4)	11 (0.9)	
Surgical assistant (number, %)						
Consultant	288 (9.6)	162 (11.1)	0.050	232 (10.0)	123 (10.0)	0.001
Other	2720 (90.4)	1299 (88.9)		2091 (90.0)	1113 (90.0)	
Surgical approach (number, %)						
Deltopectoral	2757 (91.7)	1323 (90.6)	0.176	2135 (91.9)	1141 (92.3)	0.071
Deltoid detachment	4 (0.1)	2 (0.1)		3 (0.1)	2 (0.2)	
Other	1 (0.0)	2 (0.2)		1 (0.0)	2 (0.2)	
Posterior	4 (0.1)	8 (0.5)		4 (0.2)	1 (0.1)	
Superior (Mackenzie)	153 (5.1)	104 (7.1)		134 (5.8)	70 (5.7)	
Trans-deltoid	89 (3.0)	22 (1.5)		46 (2.0)	20 (1.6)	
Unit type (number, %)						
NHS	2953 (98.2)	1435 (98.2)	0.004	2283 (98.3)	1215 (98.3)	0.002
Independent	55 (1.8)	26 (1.8)		40 (1.7)	21 (1.7)	
Cases / yr (mean, SD)	10.7 (5.9)	8.6 (5.8)	0.364	9.5 (5.4)	9.2 (6.0)	0.066
Charlson Comorbidity Index(mean, SD)	1.4 (1.8)	1.4 (1.8)	0.018	1.4 (1.7)	1.4 (1.7)	0.013
Deprivation level (number, %)						
Least deprived	990 (33.4)	491 (33.7)	0.079	799 (34.4)	420 (34.0)	0.020
Less deprived	952 (32.2)	436 (30.0)		708 (30.5)	377 (30.5)	
More deprived	699 (23.6)	337 (23.2)		547 (23.5)	288 (23.3)	
Most deprived	320 (10.8)	191 (13.1)		269 (11.6)	151 (12.2)	

Table 5. Characteristics pre- and post-matching, patients age over 75 years.

Model parameters for revision and reoperation in patients aged 60 years and younger – Weibull regression relative hazard

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	0.0086	0.0770
Cons (β_0)	-3.4911	0.8001
Age (β_1)	-0.0148	0.0144
Male (β_2)	-0.2287	0.1755
implant-hemi (β_3)	0.7419	0.1839

Table 6. Model parameters – revision, patients aged 60 years and younger

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	-0.2743	0.0884
cons($\boldsymbol{\beta_0}$)	-3.4562	0.9107
age($\boldsymbol{\beta_1}$)	-0.0116	0.0165
male($\boldsymbol{\beta_2}$)	-0.1812	0.1982
implant-hemi($\boldsymbol{\beta_3}$)	0.7119	0.2051

Table 7. Model parameters – reoperation, patients aged 60 years and younger

Model parameters for revision and reoperation in patients aged 61-75 – Weibull regression relative hazard

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	-0.0093	0.0577
cons(β_0)	-2.3988	1.0769
age(β_1)	-0.0364	0.0155
male(β_2)	-0.2432	0.1406
implant-hemi(β_3)	0.7705	0.1351

Table 8. Model parameters – revision, patients aged 61-75 years

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	-0.3712	0.0738
cons(β_0)	-1.9527	1.3465
age(β_1)	-0.0423	0.0194
male(β_2)	0.0052	0.1685
implant-hemi(β_3)	0.7238	0.1732

Table 9. Model parameters – reoperation, patients aged 61-75 years

Model parameters for revision and reoperation in patients aged over 75 – Weibull regression relative hazard

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	-0.2516	0.1009
cons(β_0)	-2.9861	2.8146
age(β_1)	-0.1008	0.0354
male(β_2)	0.0674	0.2745
implant-hemi(β_3)	0.4997	0.2294

Table 10. Model parameters – revision, patients aged over 75 years

Explanatory variables	Coefficient	Standard Deviation
ln(shape param.) ln(κ)	-0.4855	0.1252
cons(β_0)	-0.7671	3.3247
age(β_1)	-0.0595	0.0285
male(β_2)	0.3546	0.1524
implant-hemi(β_3)	0.9318	0.2918

Table 11. Model parameters – reoperation, patients aged over 75 years

Cost-effectiveness acceptability curve in men

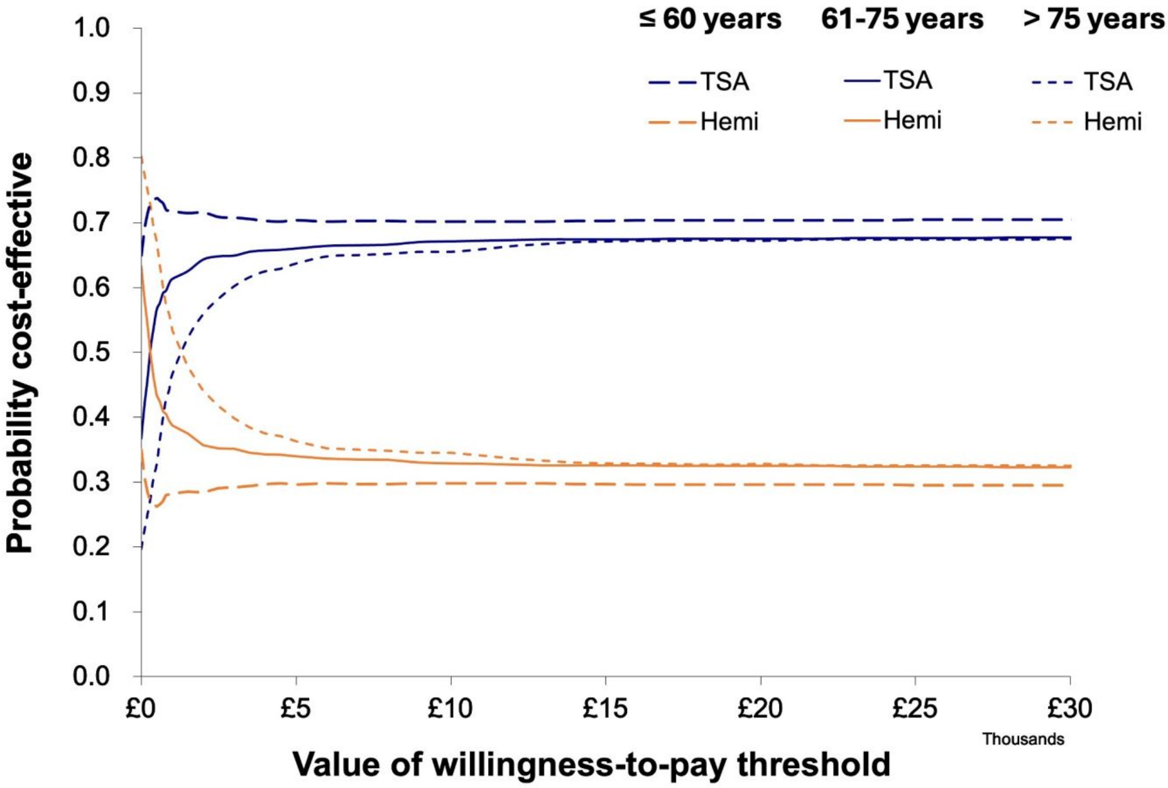

Figure 2. Cost-effectiveness acceptability curve in men.

Cost estimations

Implant costs calculated from the NJR EMBED database

Implant	Mean cost (£)	Standard deviation (£)
TSA	2306.9	381.9
HA	1652.7	535.0

Table 12. Implant costs calculated from the NJR EMBED database.

Difference in the duration of operating time for HA and TSA

An estimation of the duration of a TSA was taken from a large healthcare database (2). The mean length of a TSA was 108.30 minutes (SD 35.60 minutes). Assuming a ratio of 1:1.3 for HA:TSA (table 13) the mean duration of a HA was estimated as 83.31 minutes for an overall mean difference of 24.99 minutes. The standard deviation of the duration of a HA was assumed to be the same as a TSA (35.60 minutes).

Study	Mean operating time (minutes)		Ratio of duration of surgery TSA : HA
	TSA	HA	
Lo et al (3)	157.3	118.4	1.33
Gartsman et al (4)	98	63	1.56
Singh et al (5)	163.3	127.7	1.28
	147.8	121.9	1.21
	114.4	87.1	1.31

Table 13. Duration of operating time TSA and HA.

Duration of TSA (SD) from Testa et al	108.30 min (35.60)
Estimated ratio duration HA to TSA	1 : 1.3
Estimated duration of HA (SD)	83.31 min (24.37)
Difference in mean duration	24.99 min

The cost of an operating theatre per minute was estimated from values submitted to NHS Scotland (6). After accounting for inflation these were £18.61 per minute. The total cost difference between TSA and HA due to theatre time was £18.61*24.99 = £465.11.

Total difference in mean cost

The total difference in mean cost was the difference in the cost of the implants and the costs of theatre time.

Implant mean cost difference	£654.19
Theatre time mean cost difference	£465.11
Total difference	£1119.30

Cost of a HA = reimbursement value - (mean difference / 2) = 6016 – (1119.30/2) = £6575.65

Cost of a TSA = reimbursement value + (mean difference / 2) = 6016 + (1119.30/2) = £5456.35

The standard deviation of the total implant cost for TSA and HA was calculated from the combined variance of the costs of the implant and costs of theatre time.

Overall cost estimations

Implant	Mean cost (£)	Standard deviation (£)
TSA	6575.65	851.7
HA	5456.35	764.8
Revision shoulder (cost code HN86a)	8396	840
Re-revision shoulder (cost code HN86a)	8396	840
Reoperation (cost code HT54B)	2510	251

Table 14. Overall cost estimations

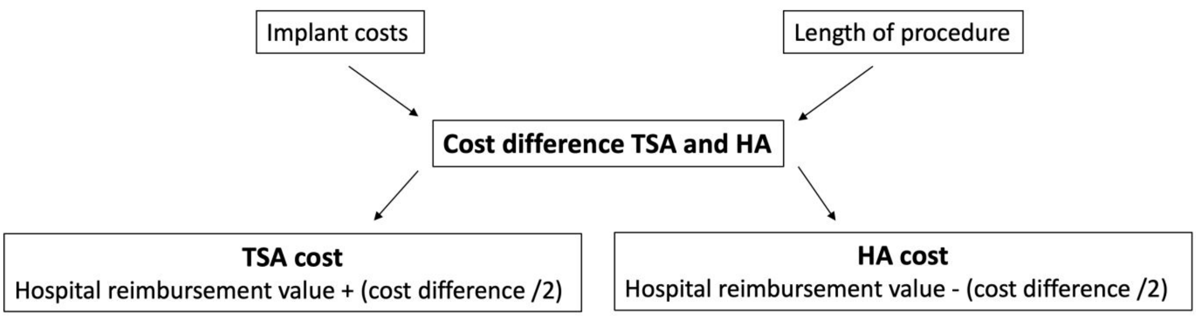

Figure 3. Adjustment of baseline cost, plus additional costs. TSA – total shoulder arthroplasty, HA – Hemiarthroplasty.

Change in costs and QALYs by age for male patients aged 60 years and younger

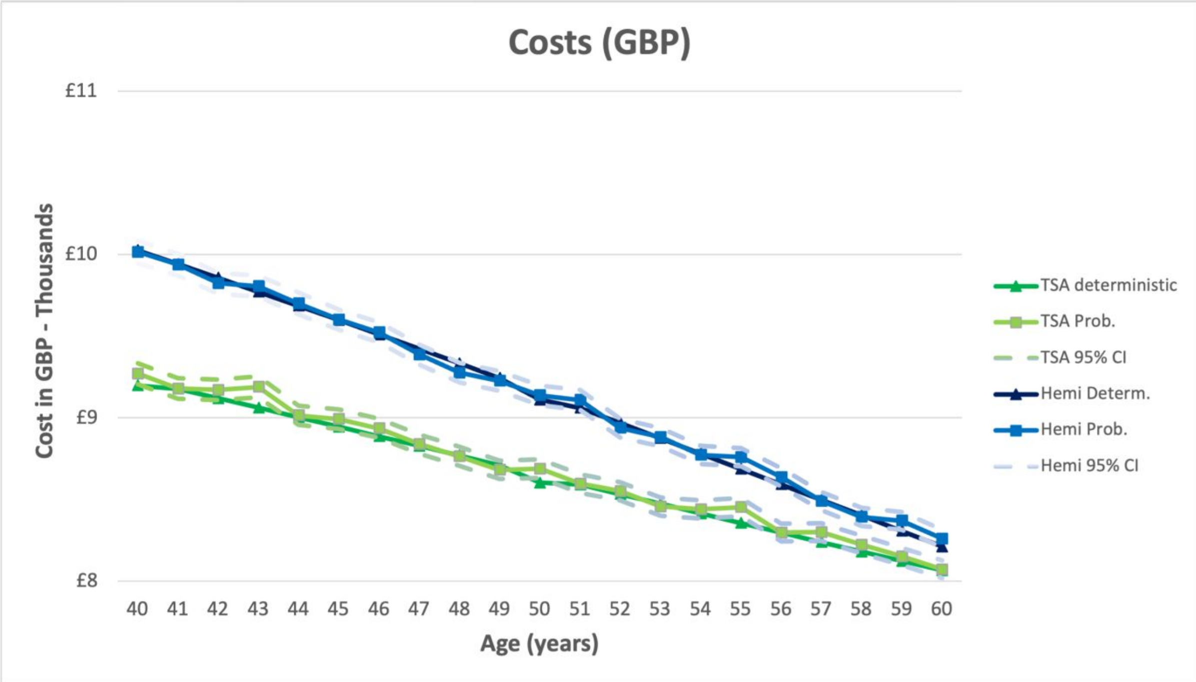

Figure 4. Costs by age for male patients aged 60 years and younger. The same trend was seen in the female cohort.

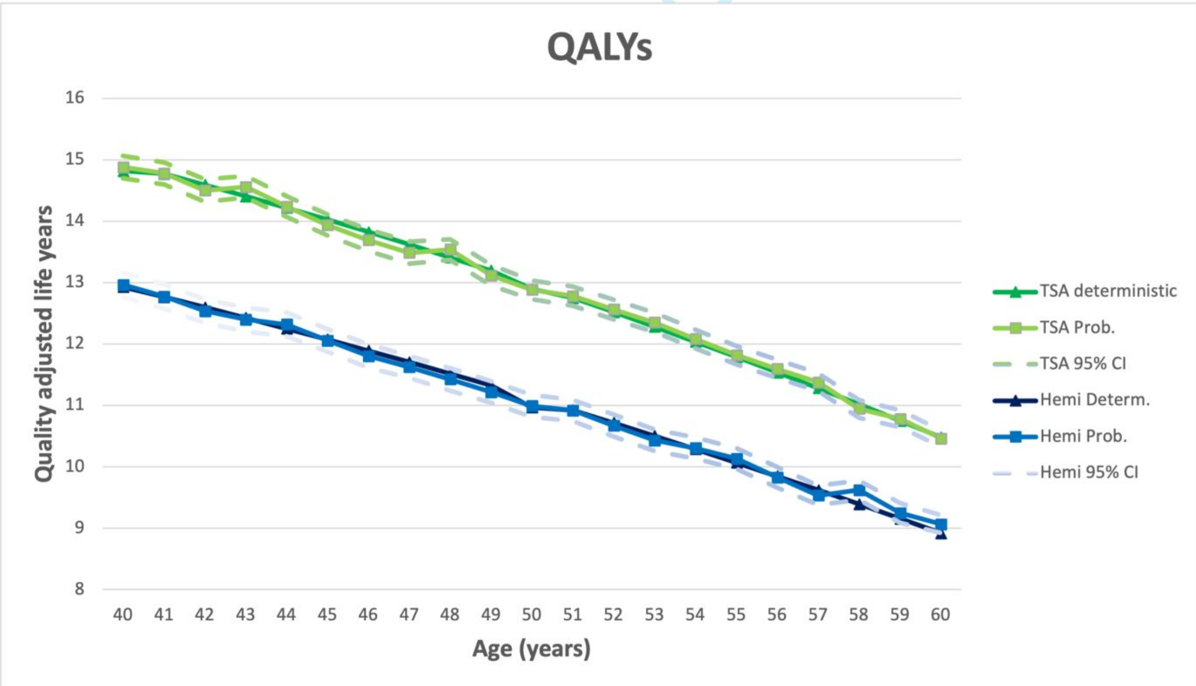

Figure 5. Quality-adjusted life years by age for male patients aged 60 years and younger. The same trend was seen in the female cohort.

CHEERS 2022 Checklist

Topic	No.	Item	Location where item is reported
Title			
	1	Identify the study as an economic evaluation and specify the interventions being compared.	Page 1
Abstract			
	2	Provide a structured summary that highlights context, key methods, results, and alternative analyses.	Pages 2&3
Introduction			
Background and objectives	3	Give the context for the study, the study question, and its practical relevance for decision making in policy or practice.	Pages 4&5
Methods			
Health economic analysis plan	4	Indicate whether a health economic analysis plan was developed and where available.	Submitted to the National Joint Registry
Study population	5	Describe characteristics of the study population (such as age range, demographics, socioeconomic, or clinical characteristics).	Page 6
Setting and location	6	Provide relevant contextual information that may influence findings.	Page 6
Comparators	7	Describe the interventions or strategies being compared and why chosen.	Page 4
Perspective	8	State the perspective(s) adopted by the study and why chosen.	Page 6
Time horizon	9	State the time horizon for the study and why appropriate.	Page 6
Discount rate	10	Report the discount rate(s) and reason chosen.	Page 10
Selection of outcomes	11	Describe what outcomes were used as the measure(s) of benefit(s) and harm(s).	Pages 7-9
Measurement of outcomes	12	Describe how outcomes used to capture benefit(s) and harm(s) were measured.	Pages 7-9
Valuation of outcomes	13	Describe the population and methods used to measure and value outcomes.	Pages 7-11

Topic	No.	Item	Location where item is reported
Measurement and valuation of resources and costs	14	Describe how costs were valued.	Pages 9&10, appendix
Currency, price date, and conversion	15	Report the dates of the estimated resource quantities and unit costs, plus the currency and year of conversion.	Pages 9&10, appendix
Rationale and description of model	16	If modelling is used, describe in detail and why used. Report if the model is publicly available and where it can be accessed.	Pages 6-8, 10&11
Analytics and assumptions	17	Describe any methods for analysing or statistically transforming data, any extrapolation methods, and approaches for validating any model used.	Pages 7-11
Characterising heterogeneity	18	Describe any methods used for estimating how the results of the study vary for subgroups.	Page 11
Characterising distributional effects	19	Describe how impacts are distributed across different individuals or adjustments made to reflect priority populations.	Page 11
Characterising uncertainty	20	Describe methods to characterise any sources of uncertainty in the analysis.	Pages 10&11
Approach to engagement with patients and others affected by the study	21	Describe any approaches to engage patients or service recipients, the general public, communities, or stakeholders (such as clinicians or payers) in the design of the study.	Page 21
Results			
Study parameters	22	Report all analytic inputs (such as values, ranges, references) including uncertainty or distributional assumptions.	Page 14
Summary of main results	23	Report the mean values for the main categories of costs and outcomes of interest and summarise them in the most appropriate overall measure.	Page 12
Effect of uncertainty	24	Describe how uncertainty about analytic judgments, inputs, or projections affect findings. Report the effect of choice of discount rate and time horizon, if applicable.	Pages 12-17
Effect of engagement with patients and others affected by the study	25	Report on any difference patient/service recipient, general public, community, or stakeholder involvement made to the approach or findings of the study	Not reported
Discussion			

Topic	No.	Item	Location where item is reported
Study findings, limitations, generalisability, and current knowledge	26	Report key findings, limitations, ethical or equity considerations not captured, and how these could affect patients, policy, or practice.	Pages 18-20
Other relevant information			
Source of funding	27	Describe how the study was funded and any role of the funder in the identification, design, conduct, and reporting of the analysis	Page 21
Conflicts of interest	28	Report authors conflicts of interest according to journal or International Committee of Medical Journal Editors requirements.	Page 21

From: Husereau D, Drummond M, Augustovski F, et al. Consolidated Health Economic Evaluation Reporting Standards 2022 (CHEERS 2022) Explanation and Elaboration: A Report of the ISPOR CHEERS II Good Practices Task Force. Value Health 2022;25. doi:10.1016/j.jval.2021.10.008

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