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Total knee arthroplasty in patients with severe obesity provides value for money despite increased complications

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Aims

Access to total knee arthroplasty (TKA) is sometimes restricted for patients with severe obesity (BMI ≥ 40 kg/m²). This study compares the cost per quality-adjusted life year (QALY) associated with TKA in patients with a BMI above and below 40 kg/m² to examine whether this is supported.

Methods

This single-centre study compared 169 consecutive patients with severe obesity (BMI ≥ 40 kg/m²) (mean age 65.2 years (40 to 87); mean BMI 44.2 kg/m² (40 to 66); 129/169 female) undergoing unilateral TKA to a propensity score matched (age, sex, preoperative Oxford Knee Score (OKS)) cohort with a BMI < 40 kg/m² in a 1:1 ratio. Demographic data, comorbidities, and complications to one year were recorded. Preoperative and one-year patient-reported outcome measures (PROMs) were completed: EuroQol five-dimension three-level questionnaire (EQ-5D-3L), OKS, pain, and satisfaction. Using national life expectancy data with obesity correction and the 2020 NHS National Tariff, QALYs (discounted at 3.5%), and direct medical costs accrued over a patient's lifetime, were calculated. Probabilistic sensitivity analysis (PSA) was used to model variation in cost/QALY for each cohort across 1,000 simulations.

Results

All PROMs improved significantly ($p < 0.05$) in both groups without differences between groups. Early complications were higher in BMI ≥ 40 kg/m²: 34/169 versus 52/169 ($p = 0.050$). A total of 16 (9.5%) patients with a BMI ≥ 40 kg/m² were readmitted within one year with six reoperations (3.6%) including three (1.2%) revisions for infection. Assuming reduced life expectancy in severe obesity and revision costs, TKA in patients with a BMI ≥ 40 kg/m² costs a mean of £1,013/QALY (95% confidence interval £678 to 1,409) more over a lifetime than TKA in patients with BMI < 40 kg/m². In PSA replicates, the maximum cost/QALY was £3,921 in patients with a BMI < 40 kg/m² and £5,275 in patients with a BMI ≥ 40 kg/m².

Conclusion

Higher complication rates following TKA in severely obese patients result in a lifetime cost/QALY that is £1,013 greater than that for patients with BMI < 40 kg/m², suggesting that TKA remains a cost-effective use of healthcare resources in severely obese patients where the surgeon considers it appropriate.

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Introduction

Obesity is a significant risk factor for the development of knee osteoarthritis (OA), for which total knee arthroplasty (TKA) is a common treatment for end-stage OA.[1] Rates of OA and consequential number of TKAs performed annually in the UK are projected to dramatically increase by 2030.[2] This can be attributed to both an ageing population and an increasing prevalence of obesity, in particular severe class III obesity, defined as a BMI of ≥ 40 kg/m².[2,3] Patients with both knee OA and class III obesity have a 2.7-fold increased risk of requiring

Table I. Costs of total knee arthroplasty in patients with a BMI ≥ and < 40 kg/m², including managing associated complications that had occurred within one year.[19]

Cohort	n	HRG code	Description	Unit cost, £	Total, £
BMI ≥ 40 kg/m²					
Primary admission					
TKA (LOS ≤ 8 days)	169	HN22D	Very major knee procedures for non-trauma with comorbidity score 2 to 3 (BPT)	6,367	1,076,023
Additional LOS (> 8 days)	57		Additional days stay	258	14,706
Reoperations					
Revision TKA or DAIR (LOS < 34 days)	3	HN80C	Very complex, hip or knee procedures for non-trauma, with 3 to 5 comorbidities	12,733	38,199
MUA	2	HN24B	Intermediate knee procedures for non-trauma with 2 to 3 comorbidities	1,990	3,980
Wound revision	1	HN24B	Intermediate knee procedures for non-trauma with 2 to 3 comorbidities	1,990	1,990
Medical admissions					
Pulmonary embolism (LOS ≤ 5 days)	4	DZ09P	Pulmonary embolus without interventions, 3 to 5 comorbidities	572	2,288
Infection (LOS ≤ 5 days)	4	WH07F	Infections or other complications of procedures, without interventions, 3 to 5 comorbidities	1,188	4,752
Stroke (LOS ≤ 18 days)	1	AA35F	Stroke with 0 to 3 comorbidities	2,555	2,555
Atrial fibrillation (LOS ≤ 5 days)	1	EB07E	Arrhythmia or conduction disorders, with 0 to 3 comorbidities	557	557
Extra LOS	19		Additional days	230	4,370
Other investigations					
Doppler USAS	14	RD42Z	Ultrasound scan with duration of 20 mins and over, without contrast	50	700
			Total costs at 1 yr		1,150,120
			Per patient cost at 1 yr		6,805
			Lifetime cohort estimated cost of revision		244,919
			Lifetime total cost		1,395,039
			Per patient lifetime cost		8,255
BMI < 40 kg/m²					
Primary admission					
TKA (LOS ≤ 8 days)	169	HN22E	Very major knee procedures for non-trauma with comorbidity score 0 to 1 (BPT)	6,068	1,025,492
Additional LOS (> 7 days)	79		Additional days stay	258	20,382
Reoperations					
Revision TKA or DAIR (LOS < 34 days)	4	HN80D	Very complex, hip or knee procedures for non-trauma, with 0 to 2 comorbidities	10,004	40,016
MUA (LOS ≤ 5 days)	3	HN24C	Intermediate knee procedures for non-trauma with 0 to 1 comorbidities	1,800	5,400
Secondary patella resurfacing (LOS ≤ 8 days)	2	HN22E	Very major knee procedures for non-trauma with comorbidity score 0 to 1 (BPT)	6,068	12,136
Arthroscopic biopsy	1	HN24C	Intermediate knee procedures for non-trauma, with 0 to 1 comorbidities	1,800	1,800
Injection in theatre	1	HN26A	Minimal knee procedure for non-trauma	482	482
Medical admissions					
Pulmonary embolism (LOS ≤ 5 days)	2	DZ09Q	Pulmonary embolus without interventions, 0 to 2 comorbidities	414	828
Acute kidney injury(LOS ≤ 5 days)	1	LA07P	Acute kidney injury without interventions, 0 to 3 comorbidities	669	669
Hyponatraemia	1	KC05N	Fluid or electrolyte disorder without intervention, 0 to 1 comorbidities	284	284
Other investigations					
Doppler USAS	8	RD42Z	Ultrasound scan with duration of 20 mins and over, without contrast	50	400
SPECT	2	RN04A	SPECT scan of one area	94	188
			Total costs at 1 yr		1,108,077
			Per patient cost at 1 yr		6,557
			Lifetime cohort estimated cost of revision		200,080
			Lifetime total cost		1,308,157
			Per patient lifetime cost		7,740

BPT, best practice tariff; DAIR, debridement, antibiotic, and implant retention; HRG, healthcare resource group; LOS, length of hospital stay; MUA, manipulation under anaesthesia; SPECT, single-photon emission CT; TKA, total knee arthroplasty; USAS, ultrasound assessment.

Table II. Lifetime risk of revision following total knee arthroplasty surgery according to sex and age (adapted from Bayliss et al).[20]

Age group, yrs	Female, n	Male, n
< 55	20	35
55 to 59	14	36.5
60 to 64	16	17.5
65 to 69	6	10
70 to 74	4	5
75 to 80	2.5	3
80 to 84	1.5	1.5
≥ 85	0.5	0.5

TKA compared to patients with a normal BMI, increasing to 4.5-fold in the < 68-year age group,[4] and undergo surgery some ten years earlier than those with a normal BMI.[5]

TKA is known to improve patient-reported outcomes (PROMs) and has been demonstrated to be cost-effective.[6] However, in high BMI patients, TKA has been associated with higher postoperative complications, increased risk of revision and reduced postoperative functional improvement compared to patients with lower BMIs.[7,8] For this reason, there are currently 24 Clinical Commissioning Groups (CCGs) in the UK that restrict access for NHS-funded care to arthroplasty for patients with a BMI ≥ 40 kg/m^2.[9] Due to the degenerative nature of OA, this strategy may result in unnecessary progressive disability in patients exceeding this threshold.[10] TKA has previously been demonstrated to be a cost-effective intervention in patients across all BMI groups.[11] To the authors' knowledge, the costs and utility associated with TKA performed in patients with severe obesity, within the UK NHS, have not previously been reported.

The primary aim of this study was to estimate the cost per quality-adjusted life year (QALY) associated with TKA in severely obese patients with a BMI ≥ 40 kg/m^2, and compare this to the cost per QALY for patients with a BMI < 40 kg/m^2, to examine if restricted access of TKA in this patient group is supported by the available data. Secondary aims were to assess complications and PROMs in severely obese patients with BMI ≥ 40 kg/m^2 up to one year following TKA.

Methods

Ethical approval was obtained for this retrospective cohort study (Scotland (A) Research Ethics Committee 16/SS/0026). Following review of a prospectively collected single-centre arthroplasty database, 169 patients with a BMI ≥ 40 kg/m^2, undergoing unilateral TKA for end-stage degenerative joint disease by eight surgeons at a large orthopaedic teaching hospital from 2013 to 2018, were included. The second of bilateral TKAs was excluded.

All patients underwent primary cemented TKAs via a medial parapatellar approach using the following implants: Triathlon cruciate-retaining (CR) (Stryker, USA) (n = 147; 87.5%); Triathlon total stabilizer (Stryker) (n = 1; 0.6%); Link Endo-Model rotational hinge (Waldemar Link, Germany) (n = 1; 0.6%); PFC Sigma CR (DePuy, USA) (n = 13; 7.7%); Medacta Sphere (Medacta, Switzerland) (n = 5; 2.9%); Attune CR (DePuy) (n = 2; 1.2%). Patient demographics were recorded. Electronic patient records were reviewed for complications (early ≤ 30 days and late > 30 days) and readmissions to hospital within one year following surgery.

Prior to TKA, and at one year following surgery, patients completed postal questionnaires including comorbidity scoring and validated PROMs: the EuroQol five-dimension three-level questionnaire (EQ-5D-3L) with general health visual analogue scale (EQ-VAS Health);[12] the Oxford Knee Score (OKS);[13,14] VAS Pain scores (0 to 100); and satisfaction, which was measured at one year using a five-point Likert scale from "very dissatisfied" to "very satisfied."[15] The EQ-5D-3L is a validated and widely used five-dimension multi-attribute general health questionnaire that defines an overall health index (from -0.594 to 1) and was scored using the crosswalk algorithm.[16] The OKS is a validated knee-specific outcome measure where 12 questions (five possible answers per question) give scores from 0 to 48 (higher scores = better function). A minimal important change (MIC) in OKS was defined as seven points.[17] Patients recorded the presence or absence of 18 comorbidities as recorded by the Charlson Comorbidity Index (CCI): myocardial infarction, heart failure, peripheral arterial disease, cerebrovascular disease, dementia, chronic obstructive pulmonary disease, connective tissue disorder, peptic ulcer, diabetes, kidney disease, hemiplegic stroke, leukaemia, malignant lymphoma, solid tumour, liver disease, AIDS, back pain, pain from other joints, and hypertension.[18]

Propensity score matching. To create a comparator group of patients with a BMI < 40 kg/m^2 who were sufficiently similar in other characteristics relevant for patient outcomes, and who underwent primary TKA during the same 2013 to 2018 time period, propensity score matching was performed in RStudio version 1.3.959 (USA) using the MatchIt package. We used propensity score matching to estimate differences between patients undergoing primary TKA with a BMI > 40 kg/m^2 (n = 169) compared to a cohort of patients with a BMI < 40 kg/m^2 (n = 169), accounting for potential confounding of sex, age, and preoperative OKS. Using the covariates, we estimated a propensity score using logistic regression which was used to perform 1:1 "nearest neighbour" propensity score matching without arthroplasty. This created two equal cohorts of 169 matched pairs for these analyses.

Costs to one year. The primary data source used to value healthcare resource use associated with TKA and the management of complications post-surgery was the NHS National Tariff payment system 2020 to 21 (Table I).[19] This data source lists the costs of treatment by number of comorbidities; for the purposes of selecting appropriate costs, the severely obese cohort were assumed to have a median of three comorbidities (including obesity), while the BMI < 40 kg/m^2 cohort was assumed to have a median of 0 comorbidities, consistent with the current study data. The best practice tariff in the presence of 2 to 3 and 0 to 1 comorbidities was therefore used for each of these groups, respectively. For each patient who required revision surgery within one year, an additional comorbidity was assumed. Patient length of stay was recorded, and any stay beyond that included in the tariff price was costed separately. Where patients were admitted to hospital for investigations (e.g. for venous thromboembolism), the cost of these investigations was assumed to be included in

Table III. Preoperative patient characteristics.

Variable	BMI ≥ 40 kg/m² (n = 169)	BMI < 40 kg/m² (n = 169)	Mean difference (95% CI)	p-value
Mean age, yrs (SD; range)	65.2 (8.0; 40 to 87)	65.3 (9.2; 33 to 88)	0.06 (-1.8 to 1.9)	0.947*
Female sex, n (%)	129 (76.3)	129 (76.3)		1.000‡
Mean preoperative OKS (SD; range)	17.3 (6.7; 3 to 32)	17.7 (7.4; 3 to 37)	0.36 (-1.2 to 1.9)	0.646*
Median BMI kg/m² (IQR)	42.9 (41.2 to 46.3)	30.8 (27.2 to 34.3)		< 0.001†
Comorbidities, n (%)				
Mean total number (range)	2 (1 to 3)	0		< 0.001†
Myocardial infarction	3 (2)	3 (2)		1.00§
Peripheral vascular disease	3 (2)	2 (1)		1.00§
COPD	3 (2)	5 (3)		0.723§
Connective tissue disorder	20 (12)	29 (17)		0.164‡
Peptic ulcer disease	3 (2)	3 (2)		1.00§
Diabetes	35 (21)	19 (11)		0.018‡
Kidney disease	4 (2)	3 (2)		1.00§
Stroke	1 (1)	3 (2)		0.623§
Back pain	79 (47)	70 (41)		0.324‡
Pain in other joints	127 (75)	116 (69)		0.045‡
Hypertension	26 (15)	9 (5)		0.024‡

*Independent-samples *t*-test.
†Mann-Whitney U test.
‡Chi-squared test.
§Fisher's exact test.
CI, confidence interval; COPD, chronic obstructive pulmonary disease; IQR, interquartile range; OKS, Oxford Knee Score; SD, standard deviation.

tariff price for admission. Conversely, any investigations that occurred as an outpatient were costed individually. Situations where reoperation had not been delivered within one year, but the complication had been diagnosed within this time period, were included.

Patient-specific lifetime risk of revision and associated costs. Each patient was assigned a probability representing their lifetime risk for revision surgery based on their age and sex according to data published by Bayliss et al[20] (Table II). The total number of expected revisions for each cohort was calculated as the sum of these probabilities. Similarly, the NHS National Tariff payment system was used to value healthcare resource use associated with revision surgery.

QALYs. Total QALYs for each patient were estimated as the difference in health state utility values using each patient's preoperative and one year post-surgery EQ-5D-3L scores, multiplied by their remaining life expectancy. According to statistics published by the Scottish Government, life expectancy in Scotland is currently 77.0 years for males and 81.1 years for females.[21] These figures are reduced by 4.6 years for males and 4.5 years for females with obesity, based on data of patients with BMI > 35 kg/m² currently aged 60 to 69.[22] QALYs were subsequently discounted at a rate of 3.5% per annum in accordance with guidelines from the National Institute for Health and Care Excellence.[23,24] Patients who were older than their estimated life expectancy at the time of surgery (n = 35) were assumed to live for one year post-surgery.

Statistical analysis. Data were analyzed using SPSS v. 25.0 (IBM, USA). Postoperative PROMs and improvement therein, and complications were compared between the BMI ≥ 40 kg/m² cohort and the propensity matched BMI < 40 kg/m² cohort (matched for age, sex, and preoperative OKS). Univariate analysis was performed using paired parametric (paired *t*-test) and non-parametric (Wilcoxon signed-rank) tests as appropriate to assess differences in continuous variables from preoperative to one-year postoperative levels. Differences in continuous variables between BMI groups were analyzed using an independent-samples *t*-test or Mann-Whitney U test according to data normality. Pearson's correlation was used to correlate continuous variables. Nominal categorical variables were assessed using chi-squared or Fisher's exact test. A p value of < 0.05 was considered statistically significant.

To determine the generalizability of these results to other potential populations, probabilistic sensitivity analysis using the Monte Carlo method was performed in Excel (Microsoft, USA) using the XLRisk package. This randomly assigns values to multiple variables simultaneously according to their distributions (e.g. mean and 95% CI), and models 1,000 such scenarios with different values for each variable. The input variables included were EQ-5D-3L gain (mean and 95% CI, normal distribution), life expectancy (mean and 95% CI, normal distribution), per patient costs of primary surgery (± 50%, normal distribution), costs of managing complications (± 50%, normal distribution) with QALYs discounted at 3.5% per year. Results were represented graphically as the probability of a cost/QALY for TKA in patients with BMI above or below 40 kg/m².

Results

Patients with BMI ≥ 40 kg/m². Patient characteristics are summarized in Table III. At one year, none of the 169 patients with BMI ≥ 40 kg/m² had died, and none were lost to follow-up. The mean age of patients undergoing TKA with BMI ≥ 40 kg/m² was 65.5 years (SD 8.3; 40 to 87) for females and 64.1 (SD 6.7; 45 to 75) for males. The majority of patients with BMI ≥ 40 kg/m² were female (n = 129; 76.3%) with mean BMI 44.2 (SD 4.2; 40 to 66), mean height 1.63 m (SD 0.1; 1.39 to 1.9), and mean weight 118.2 kg (SD 18.7; 89 to 189). Additional constraint was required in two cases (hinge n = 1; total stabilizer n = 1),

Table IV. Early (within 30 days) and late complications up to one year following total knee arthroplasty in patients with a BMI ≥ 40 kg/m² compared to a propensity matched cohort with BMI < 40 kg/m².

Complication	BMI ≥ 40 kg/m², n (%)	BMI < 40 kg/m², n (%)	p-value
Early			
Any early complication	52 (30.8)	34 (20.1)	0.050*
Acute kidney injury	3 (1.8)	2 (1.2)	1.000†
Arrhythmia/myocardial infarction	2 (1.2)	1 (0.6)	1.000†
TIA/stroke	1 (0.6)	1 (0.60	1.000†
Pneumonia	3 (1.8)	2 (1.2)	1.000†
Gastrointestinal bleed	1 (0.6)	0 (0)	1.000†
Urinary tract infection	1 (0.6)	3 (1.8)	1.000†
Confirmed VTE	6 (3.6)	1 (0.6)	< 0.001*
DVT investigated (Doppler negative)	11 (6.5)	7 (4.1)	0.123*
PE investigated (CTPA negative)	0 (0)	2 (1.2)	0.155†
Cellulitis	9 (5.3)	2 (1.2)	< 0.001†
Wound complication (persistent leakage, dehiscence, or infection)	21 (12.4)	10 (5.9)	0.099*
Clostridium difficile infection	0 (0)	1 (0.6)	1.000†
CPN injury	1 (0.6)	1 (0.6)	1.000*
Late			
Deep infection	3 (1.8)	2 (1.2)	1.000†
Stiffness requiring MUA	2 (1.2)	3 (1.8)	1.000†
Instability (after falling)	2 (1.2)	1 (0.6)	1.000†
Reoperation			
Revision within 1 yr	3 (1.8)	3 (1.8)	1.000†
Any reoperation within 1 yr	6 (3.6)	11 (6.5)	0.213*

*Chi-squared test.
†Fisher's exact test.
CPN, common peroneal nerve; CTPA, CT pulmonary angiogram; DVT, deep vein thrombosis; MUA, manipulation under anaesthesia; PE, pulmonary embolism; TIA, transient ischaemic attack; VTE, venous thromboembolism.

Table V. Reoperations for complications that were diagnosed within one year.

Cohort	Age, yrs	Sex	BMI, kg/m²	Reoperation	Time to reoperation, days
BMI < 40 kg/m² matched cohort	62	F	22.1	Secondary patella resurfacing for AKP	714
	59	M	24.4	Manipulation under anaesthetic for stiffness	62
	44	M	28.1	Polyethylene exchange for instability	304
	57	M	28.1	Revision TKA for arthrofibrosis	514
	67	F	28.2	EUA plus steroid injection	291
	65	F	31.6	Manipulation under anaesthetic for stiffness plus aspiration	343
	70	F	35.1	Secondary patella resurfacing for AKP	308
	80	F	35.6	Arthroscopic biopsy to confirm deep infection and later one-stage revision TKA	294
	73	M	35.8	Manipulation under anaesthetic for stiffness	52
	55	F	35.9	DAIR for deep infection	110
BMI ≥ 40 kg/m² cohort	61	F	40.8	Manipulation under anaesthetic for stiffness	48
	65	F	43.4	DAIR for deep infection	33
	77	F	43.6	Manipulation under anaesthetic for stiffness	78
	72	M	45.7	Wound revision for dehiscence	13
	65	F	48.6	Two-stage revision TKA for deep infection	186
	61	M	50.6	Two-stage revision TKA for deep infection	287

AKP, anterior knee pain; DAIR, debridement and implant retention; EUA, examination under anaesthetic; TKA, total knee arthroplasty.

and one required an augment and tibial stem. Median length of hospital stay was four days (IQR 4 to 6). A total of 13 patients (7.7%) exceeded an eight-day stay, incurring an additional cost for 57 additional days in hospital. Costs of TKA for the patient cohort are summarized in Table I.

Complications. Early complications (n = 64) were experienced by 52 patients (30.7%) with BMI ≥ 40 kg/m² within 30 days of TKA, 16 of whom required readmission (Tables IV and V). Wound complications occurred in 21 patients (12%) and were significantly associated with the use of non-primary implants (2/3 vs 20/166; p = 0.045, Fisher's exact test) but were not significantly associated with diabetes (3/35 vs 19/134; p = 0.380, chi-squared test) and were not associated with ultimate patient satisfaction (p = 0.460, chi-squared test). Late orthopaedic complications occurred in six patients, four of whom required reoperation within one year (Tables IV and V). No significant associations were found between deep infection and the variables collected, though the study is not powered for this.

Table VI. Patient-reported outcome measures preoperatively and at one year following total knee arthroplasty in patients with BMI ≥ 40 kg/m².

Outcome	Preoperatively	One year	Mean difference (95% CI)	p-value
Mean OKS (SD)	7.3 (6.7)	31.0 (10.5)	23.62 (12.0 to 15.2)	0.001*
Mean VAS Pain (SD)	51.6 (21.4)	33.2 (28.1)	18.4 (13.2 to 23.6)	0.001*
Median EQ VAS Health (IQR)	70.0 (50.0 to 80.7)	79.9 (59.0 to 89.0)		0.014†
Median EQ-5D-3L (IQR)	0.159 (0.05 to 0.620)	0.691 (0.576 to 0.796)		< 0.001†

*Paired *t*-test.
†Wilcoxon signed-rank test.
CI, confidence interval; EQ-5D-3L, EuroQol five-dimension three-level questionnaire; IQR, interquartile range; OKS, Oxford Knee Score; SD, standard deviation; VAS, visual analogue scale.

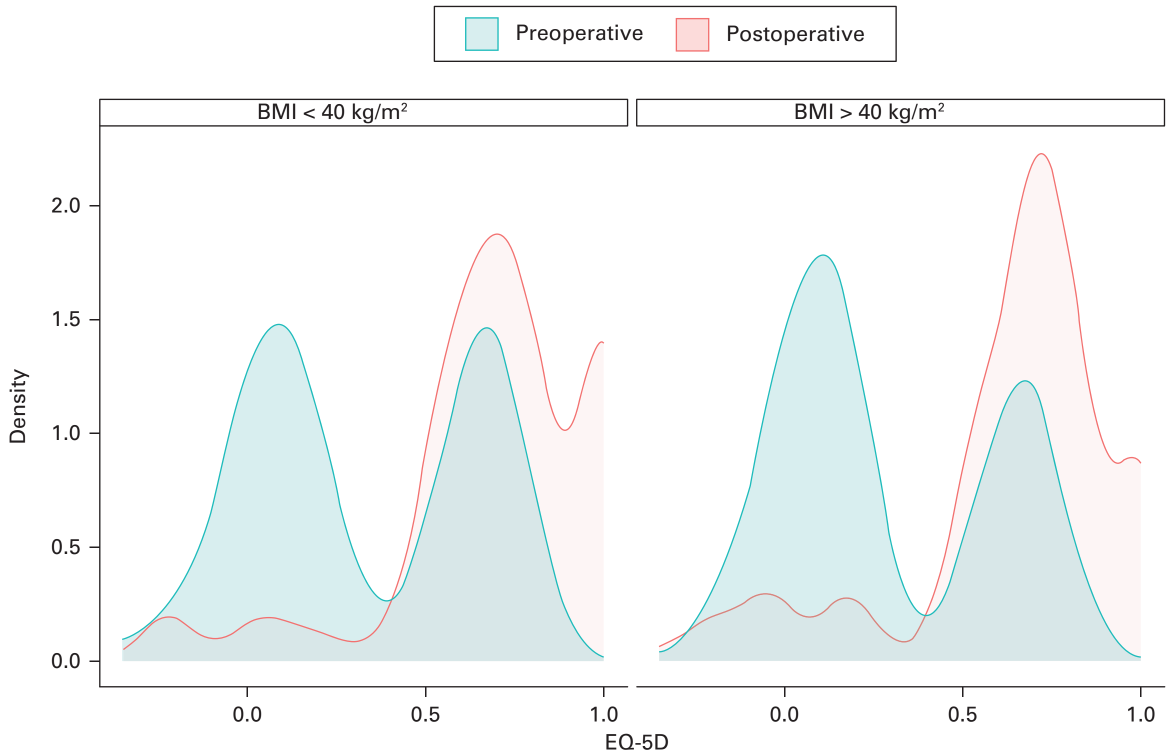

Fig. 1

EuroQol five-dimension questionnaire (EQ-5D-3L) indices preoperatively and at one year following TKA demonstrating significant improvements in both patients with BMI < 40 kg/m² and those with BMI ≥ 40 kg/m² (p < 0.001, Wilcoxon signed-rank test).

PROMs. Statistically significant improvements were recorded for each PROM following surgery (Table VI, Figure 1). Prior to TKA, 31/162 (19.1%) of patients had negative EQ-5D-3L indices. Following TKA, this reduced to 14/162 (8.6%) patients (p < 0.001, chi-squared test). However, 19 patients (11.7%) reported worse EQ-5D-3L indices at one year compared to preoperatively. A MIC in OKS of ≥ seven points was achieved in 123/169 (72.8%) patients.[15] At one year, 138/169 (81.7%) patients were satisfied or very satisfied with their TKA. Absolute BMI did not correlate with changes in any PROMs at one year: EQ-5D-3L 0.019 (p = 0.810); OKS 0.021 (p = 0.787); EQ-VAS Health 0.068 (p = 0.386); and VAS Pain 0.033 (p = 0.681, all Pearson's correlation) (Figure 2).

Costs per QALY. The mean direct medical costs one year post-surgery (i.e. surgery plus management of complications) for patients with BMI ≥ 40 kg/m² was £6,805 per patient (Table I). This figure, combined with a mean increase in health state utility values of 0.347 per patient (95% CI 0.293 to 0.401) over the same time period, estimates a cost/QALY of £19,611 (95% CI £16,970 to £23,225) at one year, assuming no change in costs or utility in the absence of treatment.

Based on the demographic characteristics of this cohort, a total of 19.24 first-time revision procedures would be expected over patients' lifetimes for a group 169 patients, at a cost of £1,449 per patient (total cost of revisions £244,919 (Table I)). The mean remaining life expectancy, adjusted for obesity, was 10.8 years (95% CI 9.72 to 12.12), and the associated QALY gain discounted over a patient's lifetime was 2.11 years (95% CI 1.68 to 2.62). Absolute BMI did not correlate with QALY gain (0.107; p = 0.175, Pearson's correlation). Therefore, the estimated cost/QALY discounted over a patient's lifetime was £3,912 (95% CI £3,151 to £4,913 (Table VII)).

Comparison to BMI < 40 kg/m² propensity matched cohort. The propensity score matching exercise used to select this cohort of patients used age, sex, and preoperative OKS as matching variables. Consequently, these variables did not show

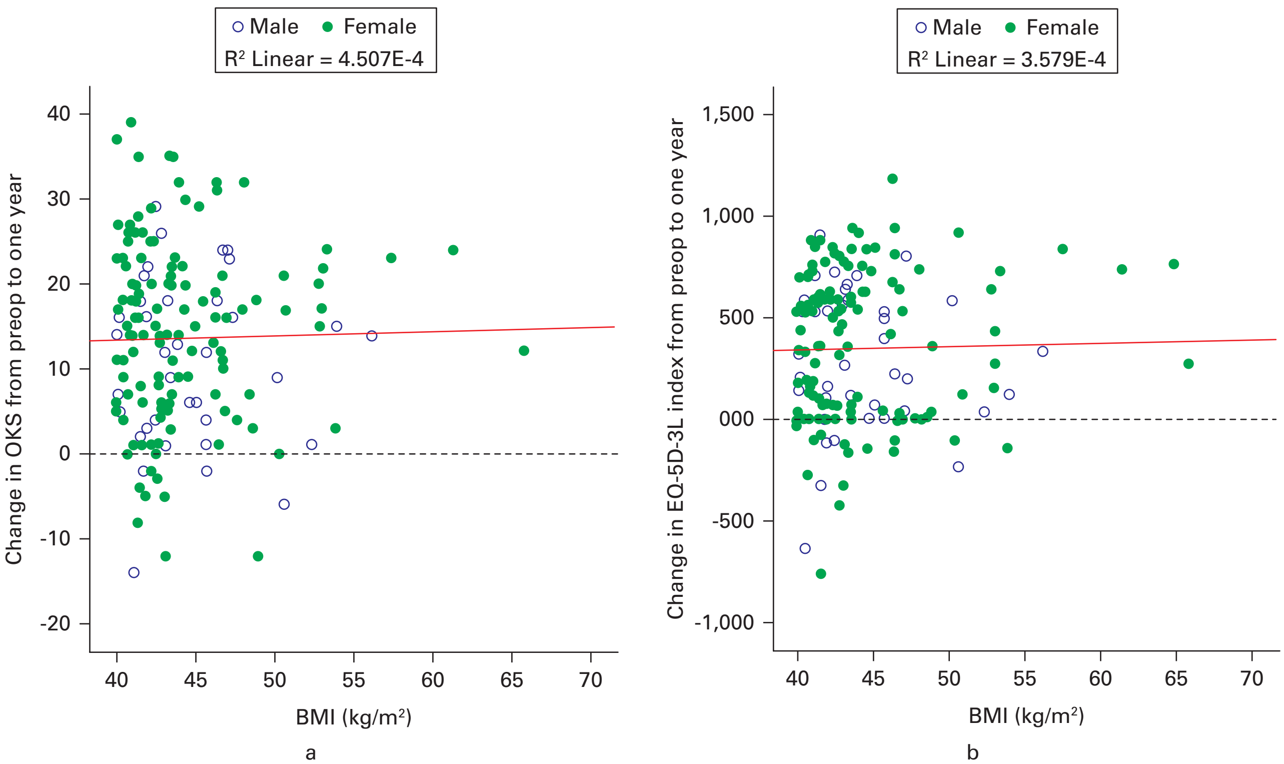

Fig. 2

Changes in a) Oxford Knee Score (OKS) and b) EuroQol five-dimension three-level questionnaire (EQ-5D-3L) from preoperative to one-year levels after total knee arthroplasty according to BMI.

Table VII. Patient-reported outcome measures before and after total knee arthroplasty in patients with BMI ≥ 40 kg/m² compared to a propensity matched cohort of patients with BMI < 40 kg/m².

Outcome	BMI ≥ 40 kg/m²	BMI < 40 kg/m²	Mean difference (95% CI)	p-value
Mean OKS change (SD)	13.6 (10.5)	15.7 (10.4)	2.11 (-0.15 to 4.37)	0.067*
Median OKS 1 yr (IQR)	32 (23 to 40)	36 (26 to 43)		0.009†
Median EQ-5D-3L change (IQR)	0.357 (0 to 0.636)	0.309 (0.071 to 0.636)		0.831†
Median EQ-5D-3L 1 yr (IQR)	0.691 (0.516 to 0.796)	0.710 (0.587 to 1.0)		0.075†
Satisfaction, n (%)				
Very satisfied	73 (43)	88 (52)		0.045‡
Satisfied	65 (38)	39 (23)		
Uncertain	19 (11)	23 (14)		
Dissatisfied	6 (4)	11 (7)		
Very dissatisfied	5 (3)	5 (3)		
Unknown	1 (1)	3 (2)		

*Independent-samples *t*-test.
†Mann-Whitney U test.
‡Chi-squared test.
CI, confidence interval; EQ-5D-3L, EuroQol five-dimension three-level questionnaire; IQR, interquartile range; OKS, Oxford Knee Score; SD, standard deviation.

statistically significant differences across cohorts, as expected (Table III). The median number of comorbidities was significantly lower in the BMI < 40 kg/m² cohort than the severely obese cohort (0 vs 2; p < 0.001, Mann-Whitney U test), and the prevalence of diabetes, hypertension, and pain in other joints was also significantly lower (Table III).

Complications within 30 days of surgery were lower in the BMI < 40 kg/m² cohort (34 vs 52; p = 0.050, chi-squared test), and numerically fewer wound complications were recorded although this was not statistically significant (p = 0.090, chi-squared test). The mean length of hospital stay was also significantly shorter (mean difference -0.905 days (95% CI -1.63 to -0.18); p = 0.014, independent-samples *t*-test).

The median OKS one year post-surgery was significantly lower in severely obese patients compared to the cohort of patients with BMI < 40 kg/m² (p = 0.009, Mann-Whitney U test; Table VII). However, improvement from preoperative OKS did not differ significantly between groups (mean difference -2.11

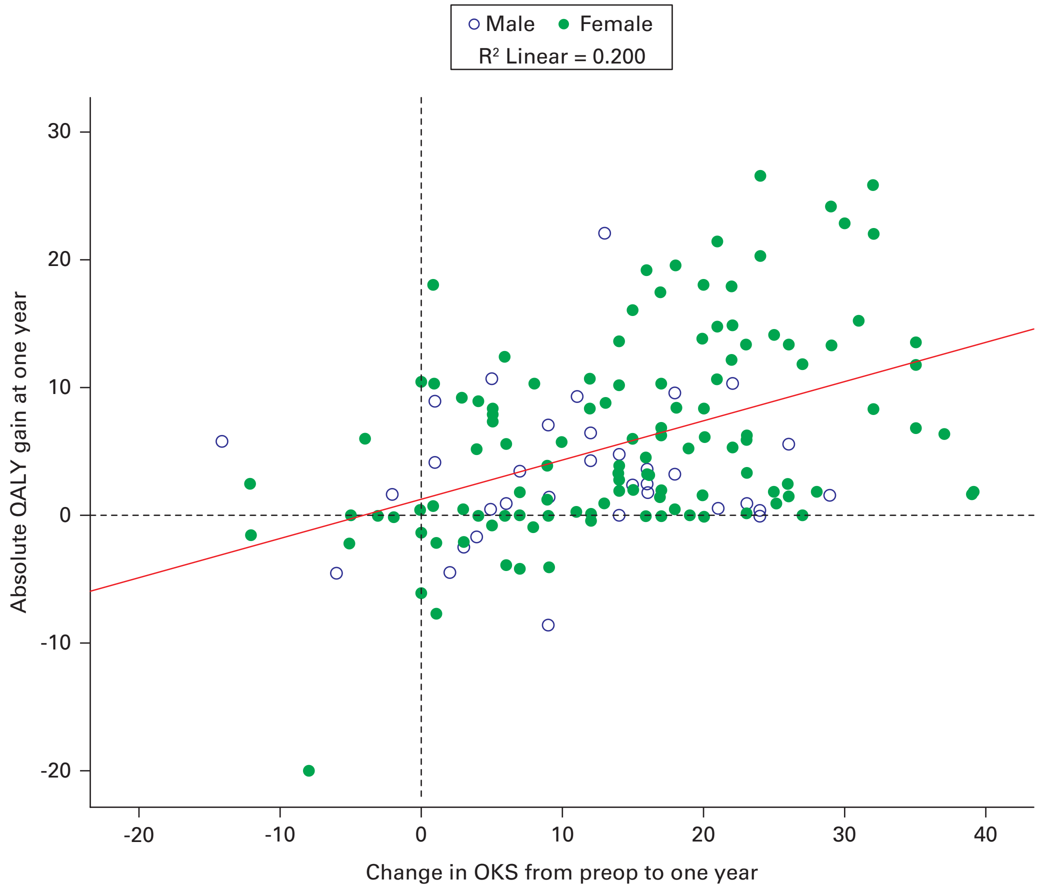

Fig. 3

Change in Oxford Knee Score (OKS) and quality-adjusted life year (QALY) gain at one year following total knee arthroplasty for patients with BMI < 40 kg/m^2 and BMI ≥ 40 kg/m^2.

(95% CI -0.15 to 4.37); p = 0.067, independent-samples *t*-test (Table VII, Figures 2 and 3)). Furthermore, there was no statistically significant difference in preoperative health state utility values across groups, or at one year post-surgery (p = 0.205, Mann-Whitney U test (Table VII, Figure 1)).

The mean direct medical costs one year post-surgery (i.e. surgery plus management of complications) for this cohort of patients was £6,557 per patient (Table I). This figure, combined with a mean increase in health state utility values of 0.352 per patient (95% CI 0.299 to 0.406) over the same time period, estimates a cost per QALY of £18,627 (95% CI £16,150 to £21,857) at one year, assuming no change in costs or utility in the absence of treatment.

Based on the demographic characteristics of this cohort, a total of 20.05 first-time revision procedures would be expected over patients' lifetimes for a group 169 patients, at a cost of £1,184 per patient (Table I). The mean remaining life expectancy for this patient group was estimated to be 15.1 years (95% CI 13.7 to 16.4), and the associated QALY gain discounted over a patient's lifetime is 2.67 years (95% CI 2.20 to 3.13). Therefore, the estimated cost per QALY discounted over a patient's lifetime is £2,899 (95% CI £2,473 to £3,504 (Table VIII)).

Probabilistic sensitivity analysis was conducted for each cohort incorporating variation in EQ-5D-3L change, life expectancy, cost of procedure, cost of complications, and 3.5% QALY discounting across 1,000 simulations is shown in Figure 4. This identified a modelled peak cost of £3,921/QALY for TKA in patients with BMI < 40 kg/m^2 and £5,275/QALY for patients with BMI ≥ 40 kg/m^2 among all bootstraps.

Discussion

TKA in patients with BMI < 40 kg/m^2 was estimated to be £91 (95% CI 51% to 148) per QALY cheaper over a lifetime than TKA in patients with BMI ≥ 40 kg/m^2 assuming equal life expectancy, and by £1,013 (95% CI 678 to 1,409) per QALY assuming reduced life expectancy in severe obesity. This includes the direct costs of the initial procedure, the management of complications incurred up to one year, and sex- and age-specific lifetime risk of revision and estimated BMI adjusted life expectancy and variations therein. PROMs improved significantly one year after TKA in patients with BMI ≥ 40 kg/m^2 with a meaningfully important change in OKS reported by 73% of patients, improved health-related quality of life in 88%, and satisfaction in 82%. There were no significant differences in OKS improvement or QALYs gained compared to propensity-matched TKA patients with BMI < 40 kg/m^2. Complication rates are high however in patients with BMI > 40 kg/m^2, with 12% of patients experiencing wound complications.[25] The

Table VIII. Quality-adjusted life years based on a lifetime cost of total knee arthroplasty of £8,255 in patients with BMI ≥ 40 kg/m² and £7,740 in patients with BMI < 40 kg/m² using both population life expectancy and corrected life expectancy corrected for BMI ≥ 40 kg/m².

Cohort	Mean QALY gain (95% CI)	Mean cost per QALY, £ (95% CI)
BMI < 40 kg/m²		
One year	0.352 (0.300 to 0.406)	18,627 (16,150 to 21,857)
Standard life expectancy		
QALY gain	5.22 (4.20 to 6.24)	1,483 (1,240 to 1,843)
Discounted 3.5%	2.67 (2.20 to 3.13)	2,899 (2,473 to 3,504)
BMI ≥ 40 kg/m²		
One year	0.347 (0.293 to 0.401)	19,611 (16,970 to 23,225)
Standard life expectancy		
QALY gain	5.42 (4.32 to 6.57)	1,523 (1,256 to 1,911)
Discounted 3.5%	2.76 (2.26 to 3.27)	2,990 (2,524 to 3,652)
Life expectancy corrected for BMI		
Corrected QALY gain	3.87 (2.97 to 4.80)	2,133 (1,720 to 2,779)
Discounted 3.5%	2.11 (1.68 to 2.62)	3,912 (3,151 to 4,913)

CI, confidence interval; QALY, quality-adjusted life year.

higher number of comorbidities, especially diabetes, in patients with severe obesity may contribute to this. Despite additional complications, reoperations, and longer hospital admissions, our estimated case-based cost/QALY of £3,912, and a modelled worst-case scenario cost/QALY of < £5,275 would indicate that TKA remains a clinically successful treatment for end-stage degenerative joint disease in patients with severe obesity where the surgeon considers it appropriate.

Previous cost-effectiveness analyses of TKA in the UK across all BMI groups have demonstrated an incremental cost-effectiveness ratio of £1,894 to £5,623 per QALY gained.[26] While it was not possible to conduct a full cost-effectiveness analysis of TKA in patients with BMI ≥ 40 kg/m² due to the lack of a nonoperative comparator arm in our study, our results find minimal differences in cost per QALY associated with TKA for patients with BMIs above and below 40 kg/m², suggesting that TKA is very likely to be cost-effective in patients with BMI > 40 kg/m². Similar to other studies, absolute BMI did not correlate with QALY gain.[26] Based on cost alone, these findings support the provision of TKA in patients with a BMI ≥ 40 kg/m². Despite being proven to be both clinically and cost-effective across all BMI groups, many Clinical Commissioning Groups (CCGs) in England and Wales restrict access to TKA.[9,27] Currently 47% of CCGs use BMI to limit access to TKA with cut-offs ranging from 25 to 40 kg/m².[9] On the contrary, the current study demonstrates that TKA in severe obesity BMI ≥ 40 kg/m² costs only £91 to £1,013/QALY more than in patients with BMI < 40 kg/m², even after factoring in the costs of managing higher complication rates.

While awaiting TKA, 19.1% of patients with BMI ≥ 40 kg/m² in the current study reported a negative preoperative EQ-5D-3L score, indicating a health state termed 'worse than death' (WTD). This is higher than the 12% reported by Scott et al[28] across all BMIs. Preoperative WTD status has been associated with lower postoperative satisfaction and OKS at one year.[28] Poorer PROMs one-year post-TKA might therefore have been expected in the present study. Though the number of patients who were very satisfied was higher in the BMI < 40 kg/m² cohort, there were also more dissatisfied/very dissatisfied patients in this group. The overall patient satisfaction of 82% among patients with BMI ≥ 40 kg/m² was within the range reported across TKAs (68% to 93%) and is reassuring with respect to operating in this patient group.[17,29] The high proportion of WTD patients among those with severe obesity may be due to associated comorbidities, or a tendency to delay surgery due to the risk of complications or anticipated weight loss. Scott et al[28] demonstrated peripheral artery disease (PAD) and connective tissue disorder (CTD) to be associated with preoperative WTD status in TKA patients. These two comorbidities were interestingly less prevalent in the current study (PAD: 1.8% and CTD: 11.8%).[30] Other studies have also noted an association between higher rates of comorbidities in obese patients and a negative impact on TKA outcome.[29,31]

The current study found high rates of postoperative complications in patients with BMI ≥ 40 kg/m²: one-third of patients in this cohort experienced a complication, including a wound complication in 12.4%. This association between BMI and TKA complications is consistent with previous study.[7,8] Amin et al[32] compared rates of postoperative complications across BMI groups, finding that 32% of morbidly obese TKA patients experienced postoperative complications, compared to 0% of patients with normal BMIs. Periprosthetic joint infections after TKA are also known to increase in incidence with increasing BMI.[7] Though higher than national figures (Table IV), the rate of VTE (3.6%) in the current study is similar to worldwide findings across all BMI groups.[33] The effect of BMI on VTE risk is debated: some studies report no correlation between BMI and postoperative VTE events;[7,33] others indicate higher rates of VTE with higher BMI.[34] The current study is underpowered to draw a definite conclusion.

An association between case complexity and wound complications, including infection, was apparent in patients with BMI ≥ 40 kg/m². Factors including a prolonged tourniquet time may have contributed to this,[35] but the numbers of patients were too small to perform meaningful analyses. The postoperative care of patients in our study did not differ from the management of those with a normal BMI. Extended oral antibiotic prophylaxis, or the use of incisional negative pressure wound therapy, could be considered in severely obese patients but would have cost implications.[36,37] However, preventing even one serious adverse event such as revision for infection may render these simple interventions cost-effective. Wound closure methods,

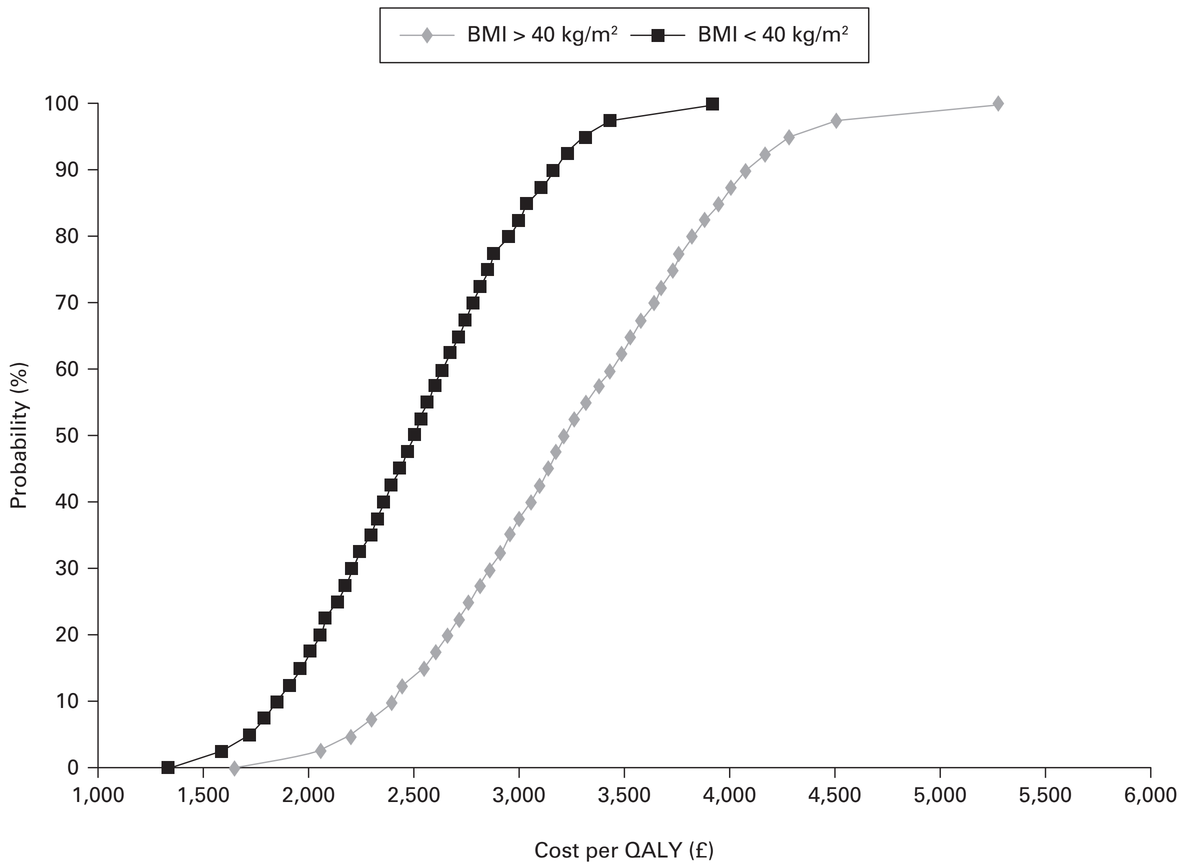

Fig. 4

Probabilistic sensitivity analysis showing the cost/quality-adjusted life year (QALY) of total knee arthroplasty in patients with BMI < 40 kg/m^2 and BMI ≥ 40 kg/m^2 in terms of probability over 1,000 simulations when QALY gain, costs, and complications are varied.

preoperative nutritional status, and albumin levels may also influence these complications but were not explored in the current study. The high rates of complications associated with severe obesity and their nature should be highlighted to patients as part of informed consent. It is also relevant to informed consent that health-related quality of life deteriorated after TKA in 12% of patients. Although 82% were satisfied, some studies have demonstrated lower satisfaction rates in patients with severe obesity.[38] Patients must be made aware of the risk for dissatisfaction following surgery and a one in ten chance of a health-state regression.

Despite well-recognized associations between complication rates, infection, and BMI,[39] no such relationship has been proven between BMI and lifetime risk of revision.[40] In a study of over 10,000 TKA procedures over ten years, Burn et al[40] concluded that BMI did not significantly affect the lifetime risk of revision of TKA. In contrast, age and sex are known to significantly affect the lifetime risk of revision of TKA.[20] For this reason, the lifetime risk of revision used in the current study was individualized based on patient sex and age rather than according to BMI.

This study has limitations, including its retrospective study design and the lack of a nonoperatively managed comparator group. Though patient-reported outcomes were collected prospectively, it is possible that complications occurred that were missed on review of electronic patient records. Propensity score matching did not include matching for comorbidities; it may be that more discretionary reoperations, such as secondary patella resurfacing and revision for stiffness, were not offered to patients with BMI ≥ 40 kg/m^2, creating a falsely elevated reoperation rate in the BMI < 40 kg/m^2 cohort by comparison. Primary care and physiotherapy attendances related to the TKA were not included in calculations of cost, and costs were not discounted over time. The costs used are the tariff paid to NHS hospitals in England and Wales, and do not represent absolute costs, which may be greater, although a 50% increase in costs was included in sensitivity analysis.[41] However, as these are the costs used by CCGs to determine which procedures to fund, they are relevant. The cost of revision TKA for deep infection is underestimated by the national tariff.[41] Costs included only the risk of first revision. Re-revisions may drive the cost up further. This study is underpowered to identify associations with specific complications. It is unknown how many patients with BMI ≥ 40 kg/m^2 were refused or declined TKA over this time period due to excessive predicted or perceived risk. The level selected for meaningful benefit may exclude patients who gain fewer points than the MIC, but are still satisfied and may include patients who reached the threshold but are unsatisfied.[17] As mentioned, to definitively determine whether TKA in patients with severe obesity is cost-effective in the NHS, a nonoperatively managed cohort would be required as a comparator in order to calculate an incremental cost-effectiveness ratio. This is impractical and costly. The current cost-utility analysis suggests that the excess costs/QALY of TKA in patients with BMI ≥ 40 kg/m^2 are unlikely to render this procedure cost-ineffective.

In conclusion, the risk of complications of TKA in patients with severe obesity is high, with nearly one-third of patients experiencing a complication, most commonly associated with their wound. However, 73% obtained a MIC following TKA and 82% were satisfied. Despite the cost of these complications, TKA in patients with severe obesity appeared to be associated with only a minor increase in lifetime cost/QALY of £91 to £1,013 relative to patients with BMI< 40 kg/m^2, suggesting that it is likely cost-effective in this population. Therefore, TKA in patients with severe obesity should not be rationed based on cost alone. Patients must be fully informed of their increased risk of complications prior to surgical intervention.

Take home message

- Total knee arthroplasty (TKA) in patients with BMI > 40 kg/m^2 is associated with a high risk of early complications (30%) and wound complications in particular (12%).
- Despite the increased risk of complications, TKA in patients with severe obesity remains cost-effective with an additional lifetime cost/QALY of £1,013 compared to patients with BMI < 40 kg/m^2.
- TKA in patients with severe obesity improves quality of life and therefore should not be rationed on the basis of cost alone.

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References

1. **Zheng H**, **Chen C**. Body mass index and risk of knee osteoarthritis: systematic review and meta-analysis of prospective studies. *BMJ Open*. 2015;5(12):e007568.
2. **Culliford D**, **Maskell J**, **Judge A**, **et al**. Future projections of total hip and knee arthroplasty in the UK: results from the UK Clinical Practice Research Datalink. *Osteoarthritis Cartilage*. 2015;23(4):594–600.
3. **Weir CB**, **Jan A**. BMI Classification Percentile And Cut Off Points. In: *StatPearls [Internet]*. Treasure Island, Florida, USA: StatPearls Publishing, 2019.
4. **Leyland KM**, **Judge A**, **Javaid MK**, **et al**. Obesity and the relative risk of knee replacement surgery in patients with knee osteoarthritis: a prospective cohort study. *Arthritis Rheumatol*. 2016;68(4):817–825.
5. **Clement ND**, **Deehan DJ**. Overweight and obese patients require total hip and total knee arthroplasty at a younger age. *J Orthop Res*. 2020;38(2):348–355.
6. **Kamaruzaman H**, **Kinghorn P**, **Oppong R**. Cost-effectiveness of surgical interventions for the management of osteoarthritis: a systematic review of the literature. *BMC Musculoskelet Disord*. 2017;18(1):183.
7. **D'Apuzzo MR**, **Novicoff WM**, **Browne JA**. The John Insall Award: Morbid obesity independently impacts complications, mortality, and resource use after TKA. *Clin Orthop Relat Res*. 2015;473(1):57–63.
8. **Sloan M**, **Sheth NP**, **Nelson CL**. Obesity and hypoalbuminaemia are independent risk factors for readmission and reoperation following primary total knee arthroplasty. *Bone Joint J*. 2020;102-B(6_Supple_A):31–35.
9. **No authors listed**. Hip and Knee Replacement: The Hidden Barriers. Association of British HealthTech Industries. 2016. https://www.abhi.org.uk/media/1379/hip-and-knee-replacement-the-hidden-barriers.pdf (date last accessed 8 February 2022).
10. **Springer BD**, **Roberts KM**, **Bossi KL**, **Odum SM**, **Voellinger DC**. What are the implications of withholding total joint arthroplasty in the morbidly obese? A prospective, observational study. *Bone Joint J*. 2019;101-B(7_Supple_C):28–32.
11. **Ponnusamy KE**, **Vasarhelyi EM**, **Somerville L**, **McCalden RW**, **Marsh JD**. Cost-effectiveness of total knee arthroplasty vs nonoperative management in normal, overweight, obese, severely obese, morbidly obese, and super-obese patients: a markov model. *J Arthroplasty*. 2018;33(7S):S32–S38.
12. **Rabin R**, **de Charro F**. EQ-5D: a measure of health status from the EuroQol Group. *Ann Med*. 2001;33(5):337–343.
13. **Dawson J**, **Fitzpatrick R**, **Murray D**, **Carr A**. Questionnaire on the perceptions of patients about total knee replacement. *J Bone Joint Surg Br*. 1998;80-B(1):63–69.
14. **Murray DW**, **Fitzpatrick R**, **Rogers K**, **et al**. The use of the Oxford hip and knee scores. *J Bone Joint Surg Br*. 2007;89-B(8):1010–1014.
15. **Scott CEH**, **Howie CR**, **MacDonald D**, **Biant LC**. Predicting dissatisfaction following total knee replacement. *J Bone Joint Surg Br*. 2010;92-B(9):1253–1258.
16. **van Hout B**, **Janssen MF**, **Feng Y-S**, **et al**. Interim scoring for the EQ-5D-5L: mapping the EQ-5D-5L to EQ-5D-3L value sets. *Value Health*. 2012;15(5):708–715.
17. **Beard DJ**, **Harris K**, **Dawson J**, **et al**. Meaningful changes for the Oxford hip and knee scores after joint replacement surgery. *J Clin Epidemiol*. 2015;68(1):73–79.
18. **Charlson M**, **Szatrowski TP**, **Peterson J**, **Gold J**. Validation of a combined comorbidity index. *J Clin Epidemiol*. 1994;47(11):1245–1251.
19. **No authors listed**. 2020/21 National tariff payment system. NHS Improvement. 2020. https://www.england.nhs.uk/wp-content/uploads/2021/02/20-21_National-Tariff-Payment-System.pdf (date last accessed 28 February 2022).
20. **Bayliss LE**, **Culliford D**, **Monk AP**, **et al**. The effect of patient age at intervention on risk of implant revision after total replacement of the hip or knee: a population-based cohort study. *Lancet*. 2017;389(10077):1424–1430.
21. **No authors listed**. Life expectancy in Scotland 2017-2019. National Records of Scotland. 2020. https://www.nrscotland.gov.uk/files//statistics/life-expectancy-in-scotland/17-19/life-expectancy-17-19-report.pdf (date last accessed 28 February 2022).
22. **Lung T**, **Jan S**, **Tan EJ**, **Killedar A**, **Hayes A**. Impact of overweight, obesity and severe obesity on life expectancy of Australian adults. *Int J Obes (Lond*). 2019;43(4):782–789.
23. **Jenkins PJ**, **Clement ND**, **Hamilton DF**, **Gaston P**, **Patton JT**, **Howie CR**. Predicting the cost-effectiveness of total hip and knee replacement: a health economic analysis. *Bone Joint J*. 2013;95-B(1):115–121.
24. **No authors listed**. The Guidelines Manual: 7 Assessing Cost Effectiveness. National Institute for Health and Care Excellence. 2012. https://www.nice.org.uk/process/pmg6/chapter/assessing-cost-effectiveness (date last accessed 8 February 2022).
25. **No authors listed**. Scottish Arthroplasty Project annual report 2020. Public Health Scotland. 2020. https://readymag.com/PHIDigital/SAP-Annual-Report-2020/ (date last accessed 28 February 2022).
26. **Dakin H**, **Gray A**, **Fitzpatrick R**, **Maclennan G**, **Murray D**, **KAT Trial Group**. Rationing of total knee replacement: a cost-effectiveness analysis on a large trial data set. *BMJ Open*. 2012;2(1):e000332.
27. **No authors listed**. Value based commissioning policies for Shropshire CCG and Telford and Wrekin CCG. NHS Shropshire CCG and NHS Telford & Wrekin CCG. 2017. https://www.shropshiretelfordandwrekinccg.nhs.uk/wp-content/uploads/Value-Based-Commissioning-Policies-for-Shropshire-CCG-and-Telford-and-Wrekin-CCG-v1.2-July19-1.pdf (date last accessed 28 February 2022).
28. **Scott CEH**, **MacDonald DJ**, **Howie CR**. 'Worse than death' and waiting for a joint arthroplasty. *Bone Joint J*. 2019;101-B(8):941–950.
29. **Bourne RB**, **Chesworth BM**, **Davis AM**, **Mahomed NN**, **Charron KDJ**. Patient satisfaction after total knee arthroplasty: who is satisfied and who is not? *Clin Orthop Relat Res*. 2010;468(1):57–63.
30. **Kamaraj A**, **To K**, **Seah KM**, **Khan WS**. Modelling the cost-effectiveness of total knee arthroplasty: a systematic review. *J Orthop*. 2020;22:485–492.
31. **Martin JR**, **Jennings JM**, **Dennis DA**. Morbid obesity and total knee arthroplasty: a growing problem. *J Am Acad Orthop Surg*. 2017;25(3):188–194.
32. **Amin AK**, **Clayton RAE**, **Patton JT**, **Gaston M**, **Cook RE**, **Brenkel IJ**. Total knee replacement in morbidly obese patients. *J Bone Joint Surg Br*. 2006;88-B(10):1321–1326.
33. **White RH**, **Romano PS**, **Zhou H**, **Rodrigo J**, **Bargar W**. Incidence and time course of thromboembolic outcomes following total hip or knee arthroplasty. *Arch Intern Med*. 1998;158(14):1525–1531.
34. **George J**, **Piuzzi NS**, **Ng M**, **Sodhi N**, **Khlopas AA**, **Mont MA**. Association between body mass index and thirty-day complications after total knee arthroplasty. *J Arthroplasty*. 2018;33(3):865–871.

35. **Olivecrona C**, **Lapidus LJ**, **Benson L**, **Blomfeldt R**. Tourniquet time affects postoperative complications after knee arthroplasty. *Int Orthop*. 2013;37(5):827–832.
36. **Newman JM**, **Siqueira MBP**, **Klika AK**, **Molloy RM**, **Barsoum WK**, **Higuera CA**. Use of closed incisional negative pressure wound therapy after revision total hip and knee arthroplasty in patients at high risk for infection: a prospective, randomized clinical trial. *J Arthroplasty*. 2019;34(3):554–559.
37. **DeFrancesco CJ**, **Fu MC**, **Kahlenberg CA**, **Miller AO**, **Bostrom MP**. Extended antibiotic prophylaxis may be linked to lower peri-prosthetic joint infection rates in high-risk patients: An evidence-based review. *HSS J*. 2019;15(3):297–301.
38. **Giesinger JM**, **Loth FL**, **MacDonald DJ**, **et al**. Patient-reported outcome metrics following total knee arthroplasty are influenced differently by patients' body mass index. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(11):3257–3264.
39. **Lenguerrand E**, **Whitehouse MR**, **Beswick AD**, **et al**. Risk factors associated with revision for prosthetic joint infection following knee replacement: an observational cohort study from England and Wales. *Lancet Infect Dis*. 2019;19(6):589–600.
40. **Burn E**, **Edwards CJ**, **Murray DW**, **et al**. The impact of BMI and smoking on risk of revision following knee and hip replacement surgery: evidence from routinely collected data. *Osteoarthr Cartil*. 2019;27(9):1294–1300.
41. **Kallala RF**, **Vanhegan IS**, **Ibrahim MS**, **Sarmah S**, **Haddad FS**. Financial analysis of revision knee surgery based on NHS tariffs and hospital costs. *Bone Joint J*. 2015;97-B(2):197–201.

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