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# Cost-utility analysis of robotic arm-assisted medial compartment knee arthroplasty

## FIVE-YEAR DATA FROM A RANDOMIZED CONTROLLED TRIAL

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### Aims
**To perform an incremental cost-utility analysis and assess the impact of differential costs and case volume on the cost-effectiveness of robotic arm-assisted unicompartmental knee arthroplasty (rUKA) compared to manual (mUKA).**

### Methods
**This was a five-year follow-up study of patients who were randomized to rUKA (n = 64) or mUKA (n = 65). Patients completed the EuroQol five-dimension questionnaire (EQ-5D) preoperatively, and at three months and one, two, and five years postoperatively, which was used to calculate quality-adjusted life years (QALYs) gained. Costs for the primary and additional surgery and healthcare costs were calculated.**

### Results
**rUKA was associated with a relative 0.012 QALY gain at five years, which was associated with an incremental cost per QALY of £13,078 for a unit undertaking 400 cases per year. A cost per QALY of less than £20,000 was achieved when ≥ 300 cases were performed per year. However, on removal of the cost for a revision for presumed infection (mUKA group, n = 1) the cost per QALY was greater than £38,000, which was in part due to the increased intraoperative consumable costs associated with rUKA (£626 per patient). When the absolute cost difference (operative and revision costs) was less than £240, a cost per QALY of less than £20,000 was achieved. On removing the cost of the revision for infection, rUKA was cost-neutral when more than 900 cases per year were undertaken and when the consumable costs were zero.**

### Conclusion
**rUKA was a cost-effective intervention with an incremental cost per QALY of £13,078 at five years, however when removing the revision for presumed infection, which was arguably a random event, this was no longer the case. The absolute cost difference had to be less than £240 to be cost-effective, which could be achieved by reducing the perioperative costs of rUKA or if there were increased revision costs associated with mUKA with longer follow-up.**

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**Keywords:** Robotic, Manual, Partial, Medial, Arthroplasty, Cost-utility

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## Introduction
Total knee arthroplasty (TKA) is an effective treatment option for end-stage arthritis of the knee, with statistically significant clinical improvements in knee-specific function and in health-related quality of life (HRQoL).[1] Manual TKA is one of the most cost-effective procedures available in the NHS with a cost per quality-adjusted life-year (QALY) of £2,101.[2] Robotic-assisted knee arthroplasty surgery is now becoming established and is associated with improved precision of implant placement, but it is not clear whether this is equates to a stastically significant

clinical improvements in functional outcomes for the patient.[3,4] More specifically in relation to unicompartmental knee arthroplasty (UKA) for medial compartment arthritis, the improved precision of implant placement offered by robotic arm-assisted surgery (rUKA) is associated with a greater early survivorship relative to manual surgery (mUKA).[5,6]

When accounting for the improved implant survival relative to mUKA and potentially the increased QALY gain relative to TKA, rUKA has been shown to be a cost-effective intervention with an incremental cost per QALY of £574 and £364, respectively.[7] However, this Markov analysis was based on the theoretical savings over the patient's lifetime, and may not reflect true costs and HRQoL differences. Dakin et al[8] recognized the limitations of using prediction modelling to estimate health gains to calculate QALY gain. They used five-year follow-up data from their randomized controlled trial (RCT; Knee Arthroplasty Trial (KAT)) to demonstrate a cost per QALY for TKA of £5,623. This cost per QALY is less than the ceiling cost of £20,000 suggested by the National Institute for Health and Care Excellence (NICE), and therefore is a cost-effective intervention.[9] To the authors' knowledge, there has been no published incremental cost-utility analysis for rUKA when considering modern costs and the 'real' revision costs, return to theatre, follow-up, and investigation costs incurred by the NHS. Establishing the cost-effectiveness is essential in the NHS to establish whether rUKA is a cost-effective procedure and not a "procedure with limited economic value."[10]

The primary aim of this manuscript was to perform a cost-utility analysis for rUKA over a five-year follow-up period with actual patient-reported QALY and costs incurred, including the costs for revision surgery during the follow-up period. The secondary aims were to: 1) assess the cost-utility of rUKA compared to mUKA when revision costs for infection were removed; 2) assess the impact of varying differential consumables costs and case volume; 3) determine the absolute cost difference that would be associated with a cost per QALY of £20,000 or less; and 4) explore a scenario where rUKA was cost neutral.

## Methods

This study follows a cohort of 139 patients who were recruited to a prospective, double-blind RCT to assess the accuracy of component positioning of rUKA compared with mUKA, and full methodological details are presented in the initial study report.[11] Functional comparisons have also been reported with one-, two-, and five-year follow-up. The five-year cost-utility analysis is presented in the current study. The study was registered on the International Standard Randomized Controlled Trial Register (ISRCTN77119437). Ethical approval was granted by the West of Scotland Research Ethics Service (Ref: 10 / S0704/12).

Patients were recruited at a single study centre (Glasgow Royal Infirmary, UK) between October 2010 and December 2012. All patients had medial OA and were deemed suitable for UKA surgery by one of three senior orthopaedic surgeons (MJGB, AM, BGJ). Inclusion criteria included patients who were suitable for a UKA for the treatment of medial osteoarthritis, the ability to give informed consent, and willingness to attend the scheduled follow-up appointments. Exclusion criteria excluded participants with ligament insufficiency, inflammatory arthritis, a deformity requiring augmentation, neurological movement disorders, pathology of the feet, ankles, hips, or opposite knee causing substantial pain or gait alterations, and patients requiring a TKA or revision surgery. Randomization was undertaken using an online system S-Plus (TIBCO Software, USA). Both patients and those researchers recording outcome measures were blinded to group allocation.

Patients were randomized to receive either a MAKO Robotic arm-assisted cemented Restoris MCK (MAKO Surgical, USA) or a cemented manual Oxford Phase 3 UKA (Zimmer Biomet, USA), using standard manual Phase 3 instrumentation. Surgical planning was carried out by the operating surgeon (MJGB, BGJ, AM) in collaboration with the MAKO technician for the robotic arm-assisted group, and digital templating was used for the conventional group. Further details of surgical techniques have been previously reported.[12]

The CONSORT diagram is presented in Figure 1. By five years, 104 (80%) patients of the original 130 who received surgery were available (55 robotic, 49 manual). In the robotic group, three patients returned at the five-year appointment having not attended at two years, six patients did not attend the five-year appointment, and a further three patients missed both appointments. In the manual group, one patient returned at the five-year appointment having not attended at two years, another seven patients did not attend the five-year appointment, and a further ten patients missed both appointments. Participants were contacted with two letters and a phone call at each timepoint (preoperative to five years postoperative), with questionnaires being completed remotely where visits were not possible. Patients were questioned on current health status as well as on healthcare usage in relation to the operated knee in the time since last review. This included visits to general practitioner (GP) and hospital, as well as investigations such as radiographs, scans, and blood tests. Further interventions including arthroscopic procedures and revisions were also recorded.

**Calculation of QALY gained.** All trial data were collected by independent research associates/research nurses at Glasgow Royal Infirmary. Patients completed the EuroQoL

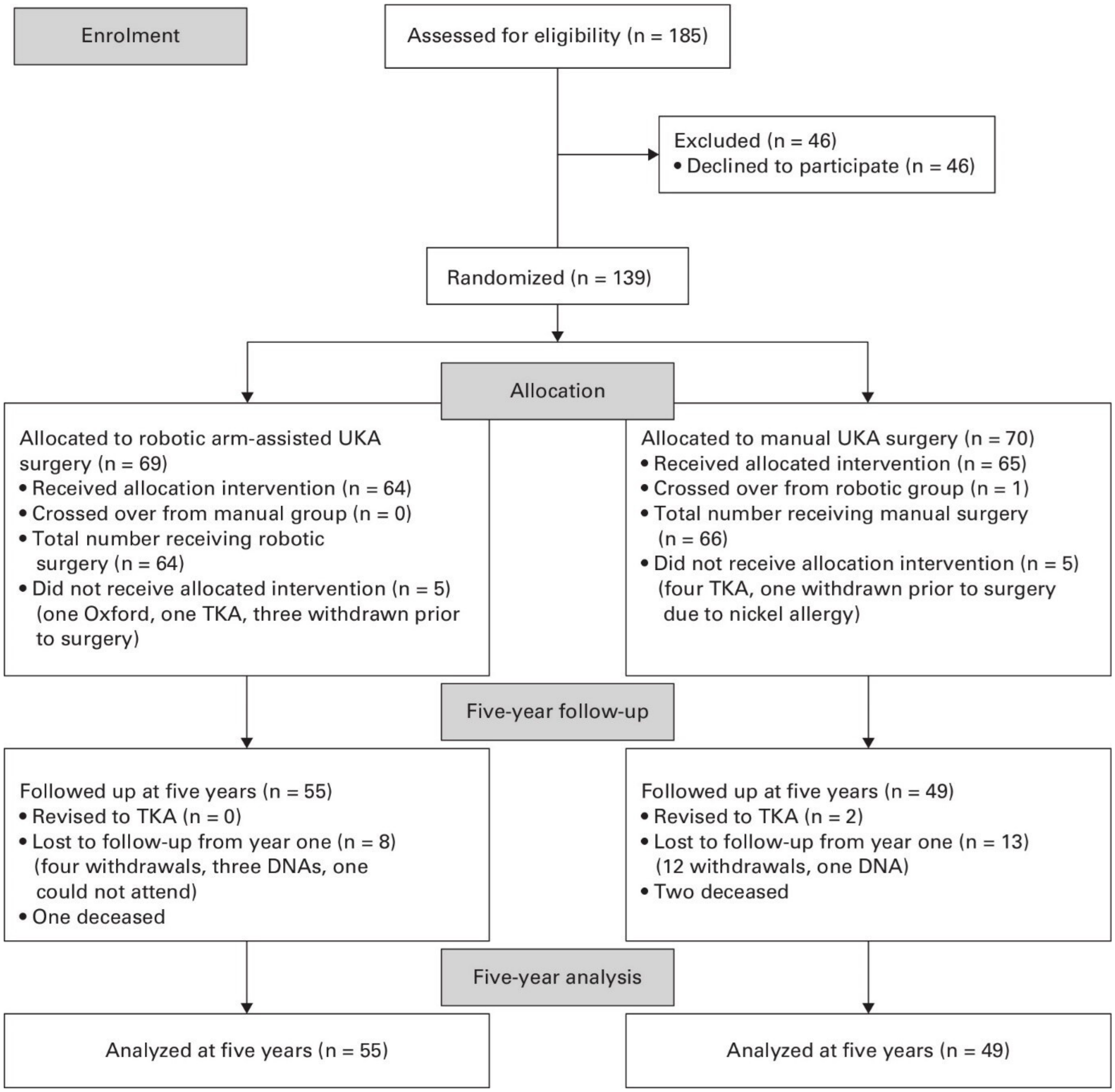


**Fig. 1**

Consolidated Standards of Reporting Trials (CONSORT) flow diagram for the study cohort. DNA, did not attend; TKA, total knee arthroplasty; UKA, unicompartmental knee arthroplasty.

(EQ) general health questionnaire preoperatively,[13] and postoperatively at three months and one, two, and five years of follow-up. The EQ general health questionnaire assesses HRQoL and evaluates five domains (5D).[14] The EQ five-dimension questionnaire (EQ-5D) assesses mobility, self-care, usual activities, pain/discomfort, and anxiety/depression. The three-level version of the EuroQoL questionnaire was used, with responses to the five domains recorded at three levels of severity (3L). This index is on a scale of -0.594 to 1; one represents perfect health, and a score less than zero represents a health state worse than death.[15] The health state, derived from the EQ-5D, was multiplied by the time spent in that state to derive the QALYs gained or lost over the study period for each of the timepoints assessed.

**Costs.** The costs were taken from the NHS best practice national tariff for 2022 to 2023 for the three-region CT scan, additional follow-up appointments, MRI scan, and additional surgery.[16] There were two available costs for knee arthroscopy depending on the complications and comorbidity (CC) scores,[17] and the lower score of 0 to 1 was employed. The tariff was assigned retrospectively using the patients' medical notes and the notes from the serious adverse events log. It was not clear what the cost of additional radiographs were from the NHS tariff, therefore costs from NICE were used.[18] The 'real'

**Table I.** Cost-utility analysis using the mean difference in the EuroQol five-dimension questionnaire (quality-adjusted life year) for robotic arm-assisted unicompartmental knee arthroplasty compared to manual, and the associated costs for both groups over the five-year follow-up period.

| Intervention | Description | Cost per item, £ | rUKA | | mUKA | | mUKA (no infection) |
|---|---|---|---|---|---|---|---|
| | | | n | Cost, £ | n | Cost, £ | Cost, £ |
| Revision | Septic | 30,011 | 0 | 0 | 1 | 30,011 | 0 |
| | Aseptic | 9,655 | 0 | 0 | 2 | 19,310 | 19,310 |
| | Arthroscopy (CC0, day case) | 1,907 | 0 | 0 | 3 | 5,721 | 5,721 |
| Follow-up | MRI | 140 | 0 | 0 | 1 | 140 | 140 |
| | Plain radiographs | 30 | 30 | 660 | 25 | 750 | 750 |
| | Follow-up clinic appointments | 68 | 30 | 2,040 | 37 | 2,516 | 2,516 |
| Robotic costs | CT (3-area) | 114 | 64 | 7,296 | N/A | N/A | N/A |
| | Robot hire cost | 288 | 64 | 18,432 | N/A | N/A | N/A |
| | Surgical consumables | 626 | 64 | 40,064 | N/A | N/A | N/A |
| | | Total | | 68,492 | | 58,448 | 28,437 |
| | | Per patient | | 1,070 | | 913 | 444 |
| | | Difference* | | - | | 157 | 626 |
| | Incremental cost per QALY of rUKA | | | | | 13,078 | 52,155 |

*Cost of robotic arm-assisted unicompartmental knee arthroplasty relative to manual per patient.
CC, compliations and comorbidity score; mUKA, manual unicompartmental knee arthroplasty; N/A, not applicable; QALY, quality-adjusted life year; rUKA, robotic arm-assisted unicompartmental knee arthroplasty.

**Table II.** Mean preoperative and postoperative EuroQol five-dimension questionnaire utilities and overall quality-adjusted life years at five years according to group.

| PROM and timepoint | Mean EQ-5D (SD) rUKA | mUKA | Mean difference (95% CI) | p-value* |
|---|---|---|---|---|
| Preoperative | 0.466 (0.297) | 0.427 (0.295) | 0.039 (-0.064 to 0.142) | 0.453 |
| 3 months | 0.713 (0.241) | 0.644 (0.261) | 0.068 (-0.020 to 0.156) | 0.127 |
| 1 year | 0.744 (0.266) | 0.728 (0.250) | 0.0161 (-0.074 to 0.106) | 0.725 |
| 2 years | 0.749 (0.279) | 0.746 (0.228) | 0.003 (-0.086 to 0.092) | 0.953 |
| 5 years | 0.704 (0.315) | 0.729 (0.273) | 0.025 (-0.078 to 0.128) | 0.632 |
| p-value† | < 0.001‡ | < 0.001§ | | |
| Overall | 3.690 (1.303) | 3.677 (1.120) | 0.012 (-0.413 to 0.437) | 0.954 |

*Independent-samples *t*-test.
†Repeated measures analysis of variance.
‡Significant for preoperative to postoperative measures (all timepoints), but no significant differences between postoperative assessments.
§Significant increase for preoperative to postoperative measures (all timepoints), and from 3 months to 1 year, but no significant differences between postoperative assessments.
CI, confidence interval; EQ-5D, EuroQol five-dimension questionnaire; mUKA, manual unicompartmental knee arthroplasty; PROM, patient-reported outcome measure; rUKA, robotic arm-assisted unicompartmental knee arthroplasty; SD, standard deviation.

costs of aseptic (£9,655) and septic (£30,011) revisions were taken from an NHS costing study from the UK in 2015,[19] rather than the tariff costs, as these were greater and would overestimate the cost per QALY. Costs for implants were assumed to be the same between the arms of the study, although there were increased costs in the rUKA group for perioperative consumables (e.g. infrared navigation trackers).

**Additional patient contact, investigations, and surgery.** Each patient was planned to receive a preoperative and three-month CT scan and preoperative, three-month, one-, two-, and five-year standard anteroposterior and lateral radiographs of the knee and one hip-knee-ankle radiograph at three months. As those receiving a mUKA would not have needed a preoperative CT scan for their surgery, this was removed from the group costs. Patients undergoing revision were identified from their medical notes at the study centre and the questionnaires during their follow-up. In addition, the national picture archiving system (PACS) for Scotland was used to review each patient's radiological history, thus if they had undergone revision in the NHS within Scotland they would have been identified. Patients' notes were assessed for additional return appointments and investigations.

**Assumptions.** Several assumptions were made to calculate the incremental cost per QALY of rUKA. First, it was assumed that the difference in the postoperative EQ-5D between the groups represented QALY difference.

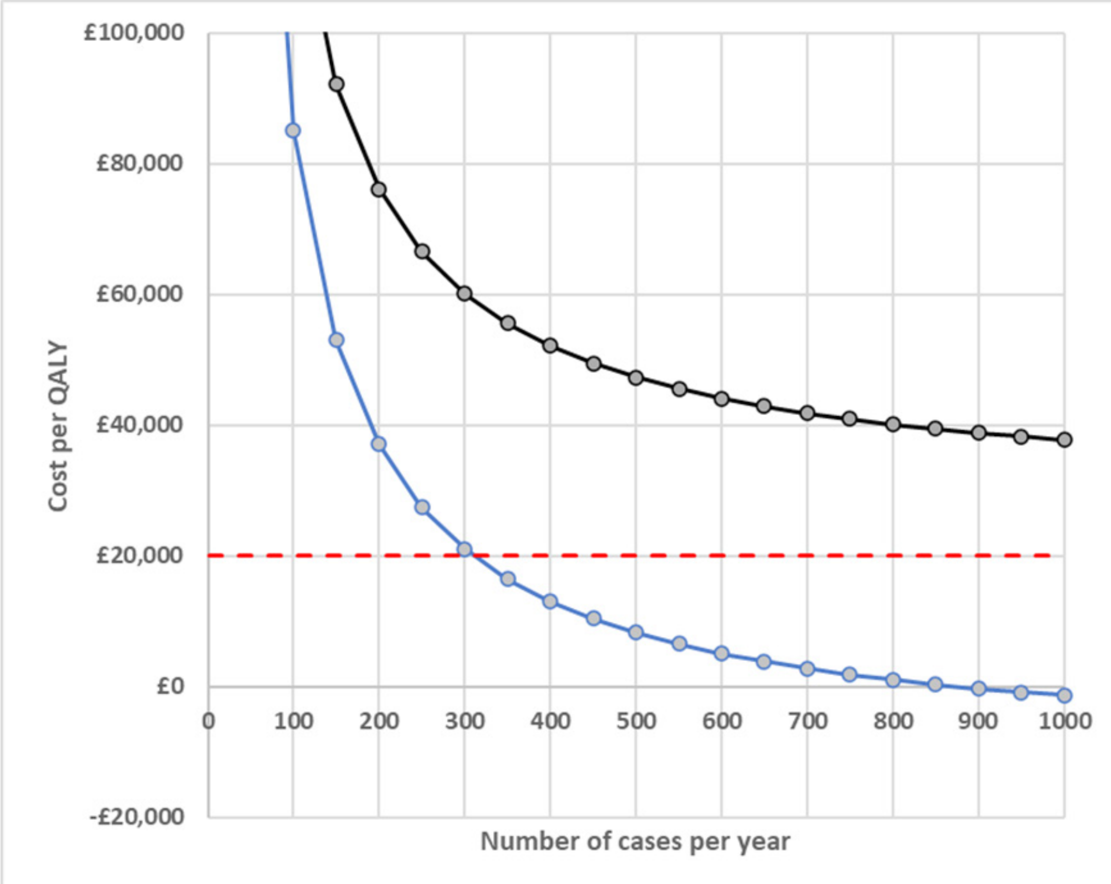


**Fig. 2**

Incremental cost per quality-adjusted life year (QALY) of robotic arm-assisted unicompartmental knee arthroplasty (rUKA) relative to manual (mUKA), when including (blue) and excluding (black) septic revision from the mUKA group. All costs included for rUKA (robot, CT scan, and consumables).

Second, the QALY gained over the first year was taken using the three-month EQ-5D for the first quarter and mean of the three-month and the one-year EQ-5D for the remaining nine months. Third, the QALY gain between two assessment timepoints (e.g. one and two years) was taken and the mean of the two points used to address potential change over this period. Fourth, patients with missing assessments were assumed to have the same QALY as that assessed at the timepoint prior to this, as they had not re-presented to the service as either a painful knee replacement or undergone a revision. Fifth, for patients undergoing revision (n = 3) or other surgical intervention (n = 3) their post-revision EQ-5D was used to model HRQoL over the remaining study period. Finally, the mortality risk was the same in both groups.

**Models.** Model 1: All costs included for both rUKA and mUKA for the study cohort with an assumed annual unit case volume of 400 (with a resultant mean average cost per patient for the robot of £288).

Model 2: All costs included for both rUKA and mUKA for the study cohort with the exclusion of the single revision for presumed infection in the mUKA, as this was a potentially random high-cost complication that may bias the results.

Model 3: Costs of the preoperative CT scan and the robot were included with the revision for infection excluded. A range of different costs for the consumables (navigation pins and reflectors) for the rUKA procedure were modelled to assess influence of this on cost per QALY with an assumed same cost for the prosthesis used.

Model 4: To identify the maximal overall differential cost between rUKA and mUKA (with the revision for infection excluded) to achieve a QALY of less than £20,000 using the difference in HRQoL observed at five years.

Model 5: A scenario where rUKA was cost-neutral (with the revision for infection excluded), where the per-patient costs of the robot and CT scan were equal to the increased postoperative costs associated with mUKA.

**Statistical analysis.** Data were analyzed using SPSS version 16 (SPSS, USA). Means are presented with standard deviations and ranges, or 95% confidence intervals if the mean represented a difference. Independent-samples *t*-test was used to detect differences between groups, and repeated measures analysis of variance (ANOVA) with

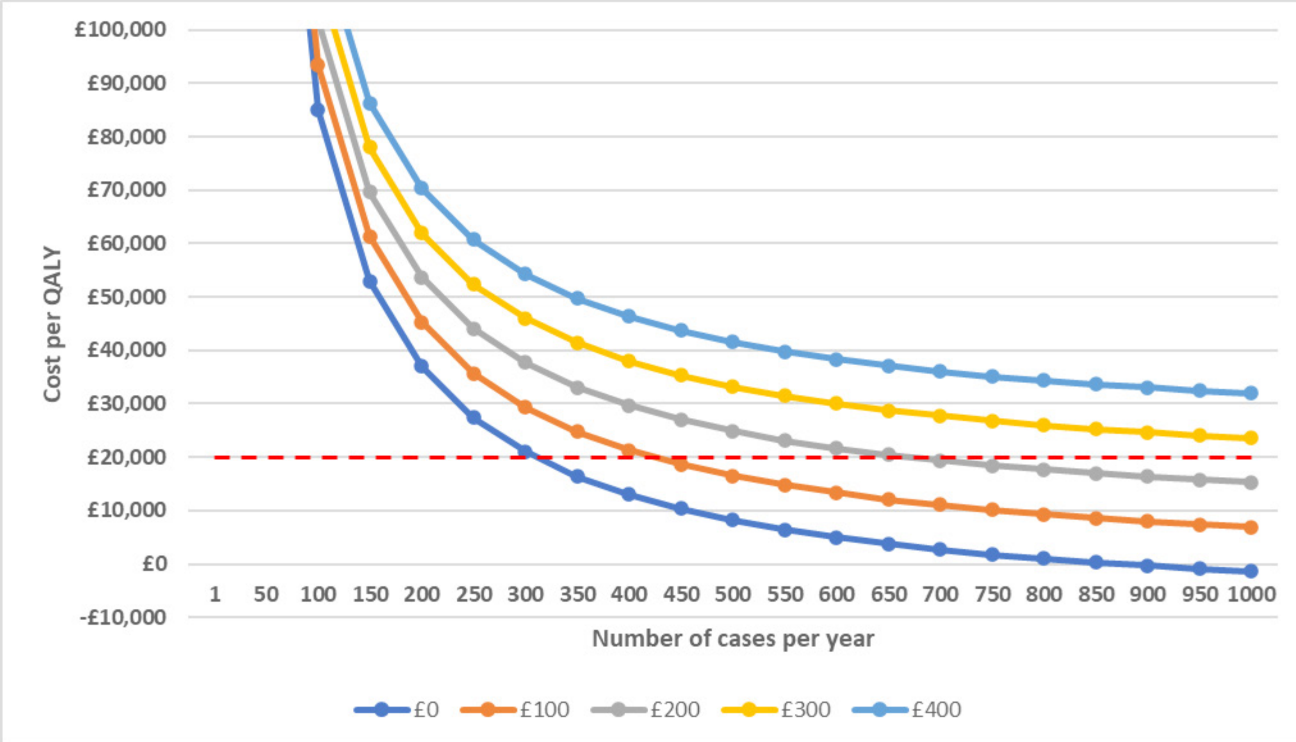


**Fig. 3**

Cost per quality-adjusted life year (QALY) of robotic arm-assisted unicompartmental knee arthroplasty (rUKA), according to number of cases performed per year and the differential costs when including the unavoidable costs of the robot and CT scans and varying the cost of the intraoperative consumables in the rUKA group from £0 to £400.

Bonferroni correction was used to assess change over time in the EQ-5D utility. Statistical significance was set at p ≤ 0.05.

## Results

There were 64 patients (n = 28, 44% female) with a mean age of 62.1 years (43 to 92) at time of primary surgery in the rUKA group, and 65 patients (n = 30, 46% females) with a mean age of 62.5 years (43 to 92) in the mUKA group (Figure 1). There were three deaths during the follow-up period. Two patients in the mUKA group were revised to TKA: one at 28 months for progression of arthritis and the other at 29 months for aseptic loosening of the tibial component. One patient in the mUKA group underwent open biopsy, polyethylene exchange, debridement for a wound dehiscence, and was managed as presumed deep infection with three months of antibiotics, however cultures were negative for organisms. There were three additional patients in the mUKA group who underwent further surgical interventions (arthroscopy of the knee). No patients in the rUKA group had received a revision or further surgical intervention. During the follow-up period, there were 55 additional plain radiographs and one MRI scan performed for clinical reasons and 67 additional follow-up appointments, which were more commonly seen in the mUKA group (Table I). There was a significant improvement in the EQ-5D utility at all postoperative assessment timepoints relative to the preoperative EQ-5D, with the greatest improvement being observed at three months postoperatively for both groups (Table II). Mean QALYs gained over the five-year study period was 1.417 (95% confidence interval 1.148 to 1.686). The overall QALY gain per patient over the five-year follow-up period was greater by 0.012 in the rUKA group relative to the mUKA group.

**Primary aim: cost per QALY.** The overall additional costs for the rUKA group as a whole were £68,492, which resulted in a cost of £1,070 per patient. Conversely, the overall additional cost for the mUKA cohort was £58,448, which resulted in a cost of £913 per patient. This resulted in a cost difference of £157 to a cost per QALY of £13,078 (Table I).

**Secondary aims.** Model 2: The cost for the single septic revision case (Model 2) was removed from the analysis, reducing the absolute cost of the mUKA group by £30,011, which increased the cost per QALY to £52,155 based on an annual unit volume of 400 cases per year (Table I). The cost per QALY was proportional to the number of cases undertaken per year, with an increasing number of cases resulting in a diminished cost of the robot per patient and therefore a lower cost per QALY (Figure 2). Using the unadjusted Model 1 (including the septic revision cost),

**Table III.** Incremental cost-effectiveness ratios for robotic arm-assisted unicompartmental knee arthroplasty relative to manual, according to the number of cases undertaken per year and the differential cost associated with the intraoperative consumables. Green being less than the £20,000 cost per quality-adjusted life year (QALY) threshold, amber being less than the £30,000 cost per QALY threshold, and red being greater than the £30,000 cost per QALY threshold.

| Number of cases per year | Intraoperative consumable costs, £ | | | | |
|---|---|---|---|---|---|
| | 0 | 100 | 200 | 300 | 400 |
| 1,000 | -1,396.09 | 6,937.24 | 15,270.57 | 23,603.91 | 31,937.24 |
| 950 | -890.83 | 7,442.50 | 15,775.84 | 24,109.17 | 32,442.50 |
| 900 | -329.43 | 8,003.91 | 16,337.24 | 24,670.57 | 33,003.91 |
| 850 | 298.02 | 8,631.36 | 16,964.69 | 25,298.02 | 33,631.36 |
| 800 | 1,003.91 | 9,337.24 | 17,670.57 | 26,003.91 | 34,337.24 |
| 750 | 1,803.91 | 10,137.24 | 18,470.57 | 26,803.91 | 35,137.24 |
| 700 | 2,718.19 | 11,051.53 | 19,384.86 | 27,718.19 | 36,051.53 |
| 650 | 3,773.14 | 12,06.47 | 20,439.80 | 28,773.14 | 37,106.47 |
| 600 | 5,003.91 | 13,337.24 | 21,670.57 | 30,003.91 | 38,337.24 |
| 550 | 6,458.45 | 14,791.79 | 23,125.12 | 31,458.45 | 39,791.79 |
| 500 | 8,203.91 | 16,537.24 | 24,870.57 | 33,203.91 | 41,537.24 |
| 450 | 10,337.24 | 18,670.57 | 27,003.91 | 35,337.24 | 43,670.57 |
| 400 | 13,003.91 | 21,337.24 | 29,670.57 | 38,003.91 | 46,337.24 |
| 350 | 16,432.48 | 24,765.81 | 33,099.14 | 41,432.48 | 49,765.81 |
| 300 | 20,000.00 | 29,337.24 | 37,670.57 | 46,003.91 | 54,337.24 |
| 250 | 27,403.91 | 35,737.24 | 44,070.57 | 52,403.91 | 60,737.24 |
| 200 | 37,003.91 | 45,337.24 | 53,670.57 | 62,003.91 | 70,337.24 |
| 150 | 53,003.91 | 61,337.24 | 69,670.57 | 78,003.91 | 86,337.24 |
| 100 | 85,003.91 | 93,337.24 | 101,670.60 | 110,003.90 | 118,337.20 |
| 50 | 181,003.90 | 189,337.20 | 197,670.60 | 206,003.90 | 214,337.20 |
| 1 | 9589004.00 | 9597337.00 | 9605671.00 | 9614004.00 | 9622337.00 |

the cost per QALY was less than £20,000 when annual unit case volume reached 300 (Figure 2). However, on removal of infection cost (Model 2) the cost per QALY did not become less than £38,000 when performing 1,000 or fewer cases per year (Figure 2).

Model 3: When assuming that the costs of the preoperative CT scan and the robot were fixed, the maximal cost of the consumables (assuming the implant costs were the same) was assessed, with removal of the infection costs for revision. A similar relationship was observed, with the cost per QALY being proportional to the number of cases undertaken per year (Figure 3). A differential cost of £0, £100, and £200 for the consumables all achieved a cost per QALY of less than £20,000 at 300, 450, and 700 cases per year (Figure 3 and Table III). Increasing the cost per QALY threshold to £30,000 at a differential cost of £300 when performing more than 650 cases per year was cost-effective (Table III).

Model 4: To ensure a cost per QALY of less than £20,000 for rUKA, the overall cost difference (total cost of rUKA (including: robot, CT scan, intraoperative consumables) minus the total cost of mUKA over the five years) could not be greater than £240 according to the QALY difference demonstrated in the current study at five years.

Model 5: rUKA was cost-neutral at 200 cases if septic revision was included and at 900 cases when septic revision was excluded. This also assumes that the cost of the consumables and rUKA implants were the same as the implant cost of the mUKA (Figure 4).

## Discussion

This study has shown that rUKA was a cost-effective intervention with an incremental cost per QALY of £13,078 relative to mUKA for the cohort assessed at five-year follow-up. However, this did include the cost of a septic revision in the mUKA group, which is potentially a random event. When removing the septic revision case, the cost per QALY was no lower than the £20,000 cost per QALY threshold no matter how many cases were performed per year. This was due to the residual cost of the preoperative CT scan, robot, and the intraoperative consumables costs. When including the cost of the CT scan and robot rUKA in the model, excluding septic revision, a differential cost of less than £200 was cost-effective, being lower than the £20,000 cost per QALY threshold when up to 700 cases per year were performed. However, an overall cost difference no greater than £240 would ensure a cost per QALY of less than £20,000 for rUKA for the QALY difference demonstrated in the current study at five years. For rUKA to be cost-neutral, the cost of the consumables needed to be zero, if the costs of the implants were assumed to be the same, and a unit performed 200 cases or more when the septic case was included, or 900 cases or more if excluded.

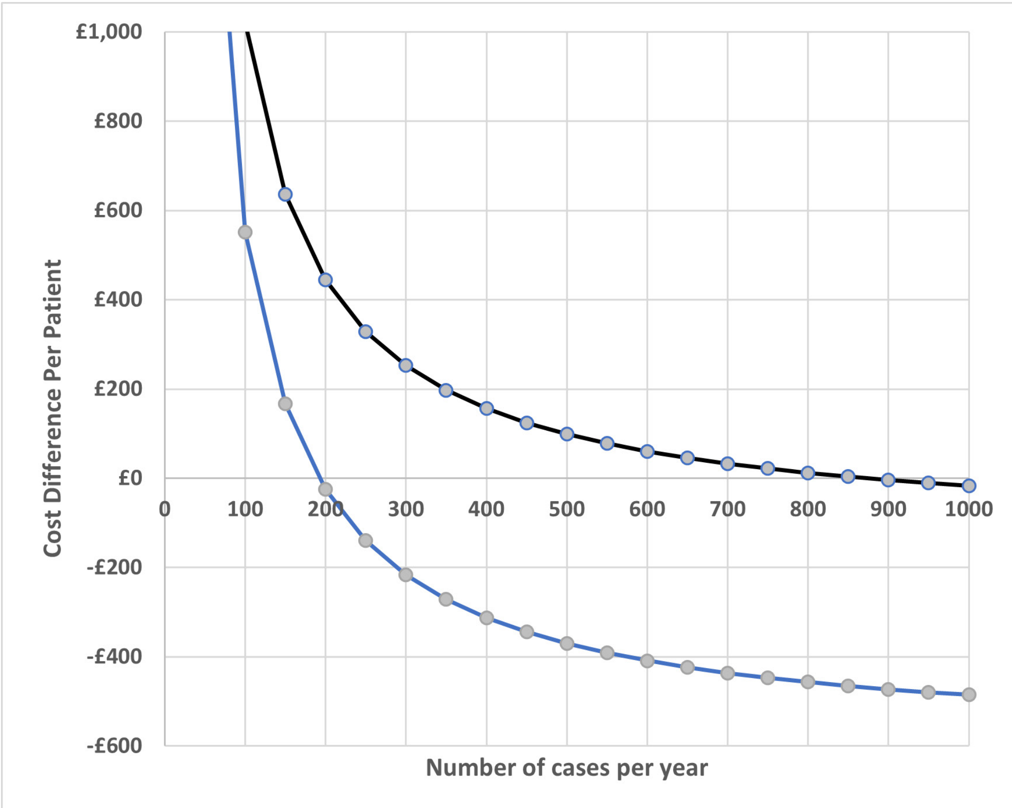


**Fig. 4**

Cost difference per patient between robotic arm-assisted unicompartmental knee arthroplasty (rUKA) and manual (mUKA) (positive = rUKA costs more; negative = rUKA costs less), according to case volume when including (blue) and excluding (black) septic revision. This includes the cost of the robot and CT scan for the rUKA group, but assumed that the cost of the implant and consumables are the same as the implant cost for mUKA.

The limitations of the study should be acknowledged. The length of follow-up was relatively short at five years, and the further potential of decreased revision risk and therefore for cost savings associated with rUKA may not have been recognized in the current study. The inclusion of debridement, antibiotics, and implant retention (DAIR) procedures for suspected infection influenced the cost per QALY in the unadjusted analysis, making rUKA a cost-effective intervention, but when removed this was not the case. Infection of a knee arthroplasty is an infrequent complication, and the rate should be theoretically no different between the rUKA and mUKA and may not be representative of a real effect of robotic surgery, i.e. a random event. Therefore, an analysis of the cost-effectiveness without the cost of the septic revision was presented to demonstrate the effect this has on cost. A second limitation was a relatively low number of patients included, which was due to the original study being powered to implant alignment, and therefore the numbers in each group were underpowered to show a statistical difference in the QALY gain of 0.012. To have demonstrated a statistically significant difference of 0.012, utility value would have required nearly 10,000 patients in each arm of the study, which would not be feasible, and for the presented cost-effectiveness analysis the assumption was made that this difference was real. The third limitation was the assumption of a standard surgical unit to undertake 400 cases per year (Model 1), and this might not reflect the actual number performed in smaller surgical units, but there is the potential to also employ the robot for total hip and total knee arthroplasty, which may reduce the cost of the robot per case. The final limitation was not accounting for the increased theatre time for rUKA when compared to mUKA, of approximately 15 minutes, which may equate to an increased cost for rUKA.[20] If two or three rUKAs were performed on a list, this may equate to an additional case being added to the list. However, rUKA was associated with a shorter length of hospital stay (p = 0.070, independent-samples *t*-test), reduced GP attendances (p = 0.092; chi-squared test), and wound problems (7 vs 22) when compared to mUKA for the current cohort. The potential cost savings of this were not included in the current models, and may offset any additional theatre time costs.[21]

An original aspect of the current study was modelling the influence of consumable costs on the cost per QALY, when the costs of the implants were assumed to be the same and that the CT scan and robot costs were fixed (revision of infection removed). This analysis suggested costs up to £200 for the consumables, which would be associated with a cost per QALY of less than £20,000 for rUKA, for centres undertaking 700 procedures or more. However, more than 900 cases per year would need to be undertaken and the intraoperative consumables cost would need to be zero to achieve a cost-neutral scenario for rUKA. In this situation, the increased perioperative cost of rUKA surgery is equal to the increased postoperative costs associated with mUKA. This number of cases may not be possible in all centres, and may support the use of rUKA in larger centres only. Furthermore, the costs of the implants (Restoris and Oxford) were assumed to be the same, which might not be the case in every surgical unit. Goh et al[20] performed a time-driven, activity-based costing analysis and demonstrated that there was a lower implant cost associated with rUKA, suggesting that implant manufacturers may negotiate lower implant costs to facilitate wider adoption of this technology. Such a cost difference could therefore absorb the cost of the intraoperative consumables associated with rUKA. This could be acknowledged as a combined cost of the implant and the consumables relative to the cost of the mUKA used.

There have been several cost-effectiveness studies for rUKA and all have shown it to be cost-effective, however these were based on Markov modelling.[7,22–24] These models have been shown to be cost-effective due to the decreased revision cost associated with rUKA when compared to mUKA, and the reported incremental cost per QALY ranged from £574[1] to £38,000.[22] This difference is likely related to the length of the follow-up (timeline) defined in the models, which varied from two years[22] to the remaining lifetime of the patient.[7] Yeroushalmi et al[24] assessed the five-year outcome of rUKA using a Markov model and found a lower incremental cost per QALY of £12,000, which is similar to that demonstrated in the current study of £13,078, when the assumed infected case was included. However, their study included data for an imageless rUKA (Navio Surgical System; Smith & Nephew, USA), which does not require a preoperative CT scan, and they also assumed that there were 12 fewer revision procedures in the rUKA for a 100-patient cohort. This revision risk (12%) at five years is greater than that observed in the current study, but their control group was from NJR data and may not reflect a true comparative cohort. In the current study, at five years the incremental cost per QALY of rUKA relative to mUKA, when the assumed infected case was excluded, was greater than £38,000, which is higher than the cost-effectiveness ceilings of £20,000 or £30,000 defined by NICE. However, if over time there is a lower revision risk associated with rUKA with longer follow-up, a further three aseptic revisions in the mUKA group and exclusion of the presumed infected revision would achieve a cost per QALY of around £14,000. However, a recent ten-year follow-up study of 366 patients undergoing rUKA (MAKO Restoris) demonstrated a survival rate of 91.7%, which is similar to that observed following mUKA.[25]

The overall mean QALY gained per patient during the five-year period of 1.417 for the study cohort was similar to that observed by Dakin et al[8] following TKA, also at five years, of 1.33, which resulted in a cost per QALY of £5,623. The TOPKAT study compared mUKA with TKA and demonstrated an increased QALY gain of 0.240 in the UKA group in addition to a cost saving of £910 at five years following surgery, leading them to conclude that UKA was more cost-effective than TKA.[26] More recently, Varughese et al[27] demonstrated rUKA to be more cost-effective than manual TKA, with an overall cost saving of $7,179 due to a shorter length of stay and less analgesia usage when compared to manual TKA. They concluded that if robotics were to promote more widespread use of rUKA as an option for surgeons who predominantly employ TKA, then cost-effectiveness had been established.

In conclusion, rUKA was a cost-effective intervention with an incremental cost per QALY of £13,078 at five years, however when removing the revision for presumed infection (mUKA group) this was no longer the case. One of the major barriers to achieving cost-effectiveness for rUKA was the additional cost of the intraoperative consumables. When this cost was zero, a unit performing 300 or more cases was cost-effective (cost per QALY < £20,000), whereas for a unit performing 900 or more robotic cases the cost of rUKA was neutral (no additional cost) at five years when compared to a unit performing a similar number of mUKA cases.

## Take home message

- Robotic arm-assisted unicompartmental knee arthroplasty (rUKA) was a cost-effective intervention with an incremental cost per quality-adjusted life-year (QALY) of £13,078 at five years.
- When removing the revision for presumed infection (manual unicompartmental knee arthroplasty (mUKA) group), this was no longer the case.
- For a unit performing 900 or more robotic cases, the cost of rUKA was neutral at five years if the consumable costs were £0.

## Twitter

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