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ORIGINAL RESEARCH

Cost-Effectiveness Analysis of Unicompartmental Knee Arthroplasty and High Tibial Osteotomy for Treatment of Medial Compartmental Osteoarthritis

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ABSTRACT

Background: Interest in unicompartmental knee arthroplasty (UKA) has recently increased in the United States concomitantly with an increase in the prevalence of physiologically active patients presenting with medial compartment osteoarthritis. This study examined the cost-effectiveness of UKA compared with high tibial osteotomy (HTO) in patients with medial compartment osteoarthritis.

Methods: A Markov decision model was constructed with review of literature to conduct a cost-utility analysis of UKA as compared to HTO in a patient population aged 40 years at the time of surgical intervention. Utility values were assigned to health states annually based on the commonly accepted reference values of 1 being "full health" and 0 being "death". These values are used to estimate quality-adjusted life years (QALYs). The Markov decision model was used to evaluate the total accumulated costs and effectiveness, measured in QALYs.

Results: The average cost of the UKA was cheaper by $842 and resulted in a significant incremental effectiveness gain compared to HTO (+ 0.96 QALY). UKA gained 20.05 QALY at a cost-effectiveness (C/E) ratio of $1048/QALY, whereas HTO gained 19.09 QALY at a C/E ratio of $1145/QALY.

Conclusion: Both UKA and HTO are cost-effective procedures but patients treated with UKA may experience an increased net health benefit over their lifetime.

Level of evidence: Economic and decision analysis level II.

Keywords: Unicompartmental, High tibial osteotomy, cost-effective arthroplasty.

INTRODUCTION

Surgical treatment for unicompartmental osteoarthritis remains a controversial issue. High tibial osteotomy for the treatment of osteoarthritis of the knee gained acceptance in the 1960s after studies by Jackson and Waugh in which redistribution of body weight from the arthritic femorotibial compartment to a healthy one was found to relieve pain.[1] Many supporting reports with various techniques on tibial osteotomy have since been published but enthusiasm for the use of high tibial osteotomy in the knee seems to have declined in the past decade.[2] This decline may be due to the excellent survival rates for total knee and unicompartmental arthroplasty with new advances in techniques and improved implants.[3,4] Price and Waite et al[5] reported a 15-year survival of 93% in 439 knees with 91% good or excellent clinical results with UKA. Other studies suggest that the good early results of HTO seem to deteriorate with time, ranging from 60 to 86% survivorship at 10 years.[6-14]

There are few well-controlled trials that have directly compared HTO to UKA. The present study extrapolates published data on the survival and function associated with each of these two treatment strategies to better identify the dominant strategy. Therefore, we set out to examine the cost-effectiveness of UKA compared with HTO on a population scale by creating a decision model for a theoretical cohort of 40-year-old patients with unicompartmental arthritis.

MATERIALS AND METHODS

General Model Overview

The health care decision model and analysis in this study was performed in accordance with the consensus-based recommendations for the conduct of cost-effectiveness analysis advocated by the panel on cost-effectiveness in health and medicine.[15] The model compared the cost-effectiveness of UKA and HTO in patients with medial compartment arthritis using a theoretical cohort of patients aged 40 years. Around 100,000 patients were analyzed in each treatment strategy in this model. The analysis was performed with a decision tree using a general decision analysis software package (TreeAge Pro Suite 2008; TreeAge Software Inc., Williamstown, Massachusetts).

Decision Model

A Markov cohort model was used to create a model for the treatment of medial compartment arthritis.[16] The decision tree consists of two principal treatment arms or strategies: UKA and HTO. A simplified schematic of the tree is shown in Figure 1. Both treatment arms and transition probabilities are consistent in design to those previously published in literature.[3,17-19] Patients with unicompartmental knee osteoarthritis undergo either UKA or HTO. After the procedure individuals remain in an initial postprocedure state for one year, either surviving or dying based on all cause and perioperative mortality (Table 1). They then transition to either the "successful HTO" or "successful UKA" health state based on the primary intervention. Cohort patients will subsequently remain in these health states until they die of natural causes or undergo revision to TKA and enter "TKA" health state. Similarly, a patient's initial intervention can fail requiring a revision procedure and transition to "TKA" health state. A portion of "successful HTO" will transition to "removal of hardware" (ROH) health transition state before transitioning to "TKA" health state. Patients may ultimately fail TKA one time and then transition to "TKA revision" health state.

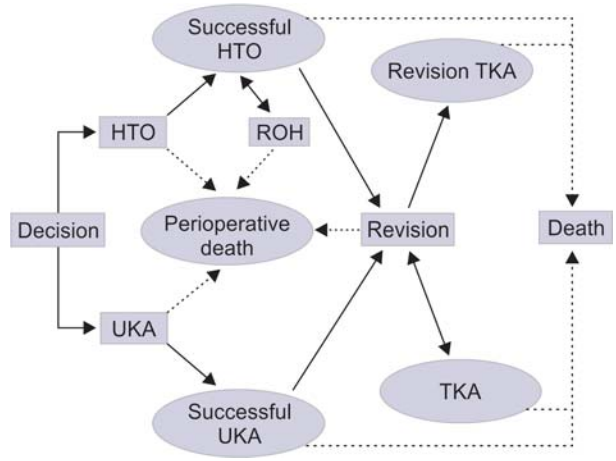

Fig. 1: Clinical pathway for the decision model. A patient can either undergo a UKA or HTO. From either of these health states patients then transition to a successful health state, fail requiring revision, or dye based on all cause and perioperative mortality.

Health states were assigned a health utility and cost value. Utility values are numeric values assigned to health states annually based on the commonly accepted reference values of 1 being "full health" and 0 being "death".[20] These values are used to estimate quality-adjusted life years (QALYs), the measure of effectiveness reported in cost-utility analyses. Cost values were assigned for the primary intervention and

Table 1: Annual model parameters used for base case

Variable	*Base case value*	*Sensitivity ranges*	*Cited literature*
Utility			
Medial compartment OA	0.7	–	3
UKA	0.9	1.0-0.8	3
HTO	Variable (0.9-0.8)	0.95-0.75	6-14,37,38
TKA	0.875	0.975-0.775	3
2nd Revision TKA	0.8	0.95-0.75	3
Disutility			
HTO	–0.15	–0.3-(–0.075)	7,39,40
Nonunion	–0.15	–0.3-(–0.075)	41-43
Hardware removal	–0.05	–0.1-(–0.025)	41-43
UKA	–0.075	–0.15-(–0.0325)	7,39,40
TKA	–0.1	–0.2-(–0.05)	3,7,36
Revision TKA	–0.15	–0.3-(–0.075)	3,7,36
Infection	–0.2	–0.1-(–0.4)	3,7,36
Cost			
HTO	$9,241	$4,620.5-18,482	
Nonunion	$9,785	$4,892.5-19,570	
Hardware removal	$8,376	$4,188-16,752	
UKA	$15,041	$7,520.5-30,082	
TKA	$15,424	$7,712-30,848	
Infection	$10,050	$5,025-20,100	
Operative Mortality			
HTO	0.0035	0-0.01	3,19,32
UKA	0.0035	0-0.01	3,19,32
TKA	0.007	0-0.0115	3,19,32
Revision TKA	0.011	0-0.2	3,19,32
Complication HTO	0.030	0.015-0.06	2
Complication UKO	0.01	0.005-0.02	3,34-36

subsequent revision procedures as the surviving cohort transitions to alternate health states based on the assigned transition probabilities. The cycle length used in this model was one year. As the theoretical patient cohort cycles through the model, costs and utilities are accumulated on a per annual basis over the lifetime of the cohort until all members of the cohort have died. Consistent with accepted health care decision analysis methods, future costs and utilities were discounted at annual rate of 3%.[21-23] The Markov decision model was used to evaluate the total accumulated costs and effectiveness, measured in QALYs, of each treatment strategy to evaluate the overall cost-effectiveness of HTO compared to UKA as the primary outcome in this patient cohort analysis.

Decision Model Assumptions

Several important assumptions were made in the construction of this model and require identification. First, we assumed the patient population defined in the model to be a theoretical cohort of healthy patients aged 40 years with medial compartmental arthritis treated with either HTO or UKA as a primary intervention. Second, we assumed that failed HTO resulted in revision to TKA, not an alternative procedure. Third, we also assumed that a percentage of the patients in the HTO arm would have a successful surgery, although some require an additional procedure for hardware removal. Fourth, we assumed the all-cause mortality of patients in the theoretical cohort following recovery from a surgical intervention to be equal to that of the general population. Fifth, we assumed failure rates, drawn from survivorship data in the literature, were annualized. Sixth, we assumed that failing HTO or UKA did not affect the utility or the survivorship of TKA as this is still debatable. Finally, a maximum of four surgical interventions (one primary procedure, removal of hardware, TKA and revision TKA) were allowed for any one patient in the Markov model.

Model Parameters

Population

We used a Markov decision model to analyze a theoretical cohort of 40-year-old patients with unicompartmental arthritis of the knee for whom medical management had failed. The cohort age was set at 40 years as this was within the age ranges identified during our literature review. Around 100,000 patients were analyzed in each treatment strategy, UKA or HTO.

Survivorship

Consistent, long-term survivorship data for TKA and UKA using modern bearing surfaces and fixation techniques for the treatment of unicompartmental arthritis is well documented in literature.[3,24-31] For our purposes, we defined survivorship as the percentage of the cohort that had not undergone a revision procedure for any reason. Based on the following study survivorship and annual all-cause probability of failure requiring revision, herein termed "failure rate", was determined. The implant survival rates for UKA, TKA and TKA revision are in accordance with earlier studies and are represented by the Kaplan-Meier curve (Fig. 2).[3,19]

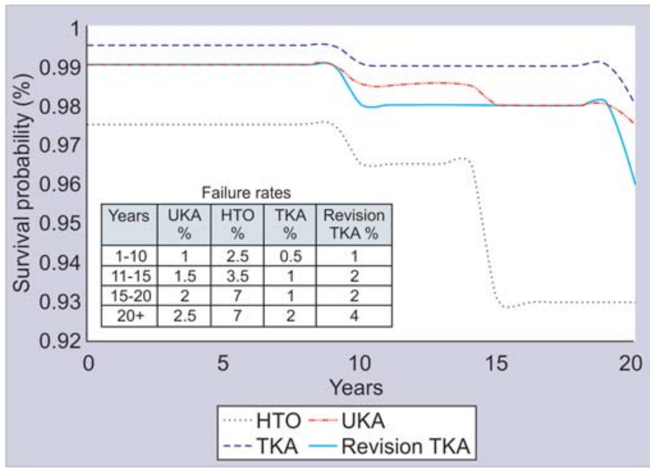

Fig. 2: The Kaplan-Meier curve represents the survivorship probabilities for the index procedures of HTO, UKA, TKA and revision TKA used in our model. The table within this figure represents the corresponding failure rates at different time intervals.

Consistent long-term survivorship data for HTO is not as well represented in the literature. In order to estimate survivorship on HTO, data was gathered from a literature search using PubMed searching high tibial osteotomy and varus osteoarthritis from 1999 to 2009 with minimum follow-up of 3.5 years, which included 25 articles (Tables 2 and 3). A review of the literature points to relative good early results that deteriorate overtime, particularly after 10 years. Naudie and Bourne et al[8] reported on a subset analysis of patients and found that better results were found in patients less than 50 years of age with flexion greater to or equal to 120°. This subset analysis was closest to our cohort such that failure rates were set at similar values. Advocates for each procedure argue that patient selection is key to success of either procedure. We felt that by using the best case scenario for survivorship of HTO make the results of this analysis represent real life practice. We set the survivorship for HTO at 2.5%. The yearly revision probability increased slightly over subsequent years spent in the successful HTO health state, consistent with evidence from the literature. Revision probabilities for all health states in the base case are represented by Kaplan-Meier graph (Fig. 2).

Mortality Rates

Perioperative mortality following primary UKA and HTO is reportedly low. The probability of perioperative death for patients undergoing TKA was estimated from a study of the Medicare population as 90-day mortality of 0.07 with revision knee replacement at 0.11.[32] We assigned the probability of perioperative death following primary UKA and HTO as 0.035 based on available data.[32] Values are shown in Table 1. Life expectancy and all-cause mortality rates were obtained from age-specific life tables.[33]

Table 2: Survivorship results of high tibial osteotomy (literature search 1999-2009, minimum 3.5 years follow-up)

Study	*# HTOs (type)*	*Age (mean years)*	*Length of follow-up (mean years)*	*Results*
Sprenger et al[6]	76 (LCW)	69 (47-81)	10.8	Survivorship 86% at 5 years, 74% at 10 years, 56% at 15 years (26 TKA)
Stukenburg Colsman et al[7]	32 (LCW)	67 (60-79)	7.5 (6.6-10)	Survivorship 60% at 7.5 years
Naudi et al[8]	106 (94 LCW, 12 dome)	55 (16-76)	14 (10-22)	Survivorship 73% at 5 years, 51% at 10 years and 39 % at 15 years, 30% at 20 years
van Raaij et al[9]	100 (LCW)	49 +/–11	Avg 12 (10-16)	Survivorship 75% at 10 years
Flamme et al[11]	101 (LCW)	58 (19-79)	10	Survivorship 81% at 10 years (19 arthroplasty)
Billings et al[12]	64 (LCW)	49 (23-69)	Avg 8.5 (5-13)	Survivorship 85% at 5 years, 53% at 10 years, (21 or 33% TKA)
Koshino et al[10]	75 (LCW)	60 (46-73)	19 (15-28)	Survivorship 95.1% at 10 years and 86.9% at 15 years
Papachristou et al[13]	44 (LCW)	Avg 51 (30-60)	10 (5-17)	Survivorship 80% at 10 years, 60% at 15 years, 52.8% at 17 years
Sterett et al[51]	33 (MOW w/microfracture)	51.3 (34-72)	Avg 3.75 (2-6.6)	Survivorship 96% at 3 years, 84% at 5 years (two failures one TKA and repeat osteotomy)
Virolainen et al meta-analysis[14]	19 studies including 2406 HTOs			Probability for conversion TKA 3.4% before 24 months, 7.8% between 24 and 47 months and 11.4% between 48 and 71 months

MOW – medial opening wedge; LCW – lateral closing wedge

Infection Rates

The probability of an infection has been established in the literature previously for TKA from prior reports as 1%.[3,34,35] We used 1% as the probability of UKA which has been used in past in such studies comparing TKA and UKA.[36] In regard to infection for HTO literature ranges from 0 to 4%.[2] We used a probability of infection of 3% with a range of 1.5 to 6% during our sensitivity analysis. Values are shown in Table 1.

Utilities

Utility values for each health state were assigned based on health-related quality of life measures. Arthritis has consistently been shown to have a utility value near 0.7.[3] We assigned utility values for UKA, TKA and revision TKA that have been validated and are consistent within prior publications.[3] Review of the literature suggested that patient-reported functional outcome measures following HTO declined with time following the intervention.[6-14,37,38] Therefore, we assigned a variable utility value for HTO starting at 0.9 (equal to UKA) and declining linearly over 20 years to a value of 0.8. Utility values used for all health states in the model are shown in Table 1.

Disutility values represent the short-term negative impact on a patient's quality of life.[20] With surgical procedures, this can include pain, immobility and non-lethal surgical complications in the postoperative and recovery periods. These transient periods of disutility are accounted for as a one-time deduction from the health-related quality of life value during the year of procedure. UKA have been reported to have a shorter time to full weight bearing, easier rehabilitation and fewer perioperative complications.[7,39,40] Ivarsson and Gillquist et al[40] reported a faster recovery in UKA when compared to HTO, but between 6 months and 1 year both groups were similar. We calculated a disutility value using the time to recovery and quality of life during recovery. For example, HTO 0 to 6 weeks utility was 0.3, 6-12 weeks 0.5, 12-24 weeks 0.7, 24 to 48 was 0.9. The utility for UKA was 0.3 for 0- 3weeks, 0.5 for 3 to 6 weeks, 0.7 for 6 to 12 weeks and 0.9 for 12 to 24 weeks. Our calculated values were similar to those used in previous Markov decision analyses[3,36] with TKA-0.1, revision due to infection –0.2, and revision TKA a disutility of –0.15. Disutility for UKA is equal to – 0.1, TKA, at –0.075, and HTO is higher than TKA, at –0.15 as a result of reports indicating prolonged recovery period and increased complications.[7] Based on expert opinion and review of literature, we set disutility for nonunion and hardware removal at –0.15.[41-43] Although controversial, we did not apply a different disutility to TKA following HTO or UKA as literature at this time does not indicate functional outcome or survivorship is any worse.[44-46] Disutility values used in the model are also shown in Table 1.

Costs

The costs of the procedures were evaluated from the payer perspective with the use of the national average Medicare reimbursement from these procedures in 2008 in US dollars with the total reimbursement including the sum of the reimbursement for the diagnosis-related group (DRG) code. The professional charges were based on the specific current procedural terminology (CPT) code for each procedure. At our

Table 3: Functional outcome results of high tibial osteotomy (literature search 1999-2009, minimum 3.5 years follow-up)

Study	*# HTO's (type)*	*Age (mean years)*	*Length of follow-up (Mean years)*	*Results*
Sprenger et al[6]	76 (LCW)	69 (47-81)	10.8	HSS score 79.6 at 5 years, 70 at 10 years and 52.6 at 15 years
Stukenburg-Colsman et al[7]	32 (LCW)	67 (60-79)	7.5 (6.6-10)	Knee Society score 71% good/excellent
Madan et al[57]	96 (LCW)	61 (24-75)	4.5 (2-14)	Modified knee score by Insall et al 71% satisfactory (i.e. excellent/good)
Flamme et al[11]	101 (LCW)	58 (19-79)	10	International knee society score 79 and function score 78, 66% better and 21% unchanged/worse
Koshino et al[10]	75 (LCW)	60 (46-73)	19 (15-28)	HSS score excellent/good 90.6% and fair/poor 9.4%
Papachristou et al[13]	44 (LCW)	Avg 51 (30-60)	10 (5-17)	HSS knee score excellent/good 83.5
Sterett et al[51]	33 (MOW w/microfracture)	51.3 (34-72)	Avg 3.75 (2-6.6)	Lysholm 78, Western Ontario and Mcmasters University Osteoarthritis Index score 16.2, Tegner 5.0
Virolainen et al[14]	19 studies including 2406 HTOs			Good/excellent result in 75.3% after 60 months and 60.3% after 100 months
				HSS knee score 94 w/excellent/good results 67%
Chaing et al[58]	19 (dome-shaped osteotomy with ex-fix)	58 (40-67)	15 (13-16)	HSS knee score excellent/good 94% (88 ± 9) at 5 years 68% (84 ± 7) at final f/u
Choi et al[59]	30 (LCW)	59 (48-70)	15.3 (10-24)	Japanese Orthopedic Association knee score 81.2 ± 15.2 w/satisfactory 60% and 13.3% TKA
Baums et al[60]	44 (MOW with ex-fix)	54 (33-66)	4 (3-5)	Excellent/good 70.5%, 29.5% fair/poor
Habata et al[61]	44 (barrel-vault or dome osteotomy w/ex-fix)	61 (44-79)	Avg 11.4 (10-20)	Japanese Orthopedic Association knee score good 68.2%, fair/poor 31.8%
Kerimoglu et al[62]	23 (dome osteotomy w/ex-fix)	60 (37-73)	5.4 (1-10)	American Knee Society score mean 80.2 ± 9.2
Koshino et al[63]	21 (MOW)	67 (55-79)	6.5 (3.2-9.5)	HSS knee 95.8 ± 4.5 f/u, American Society knee and function score 94.3 ± 7.3 and 93.1 ± 9.8 at final f/u
Kroner et al[64]	20 (LCW)	57 (41-69)	7 (6-8)	Japanese Orthopedic Association knee score 65% satisfactory 13/20
Ohsawa et al[65]	44 (osteotomy and ex-fix)	65 (49-82)	5.6 (3-9.9)	HSS knee score 86 (51-91)
Pfahler et al[66]	86 (LCW)	54 (20-67)	10.2 (6-14)	HSS score for 62 knee 87 and knee society score 86 and function score 86 28%(24/86) required TKA and were excluded
Polyzois et al[67]	107 (oblique osteotomy)	64.8(51-71)	4.5 (3.2-7.5)	HSS knee score excellent/good 73.8% fair/poor 26.2% w/4.6% TKA (5)
	95 (oblique osteotomies)	69 (53-77)	8.4 (5-11.2)	HSS knee score excellent/good 61.1% and fair/poor 38.9% w/12.6% TKA (7)
Spahn et al[68]	94 (MOW)	48.5 (31-67)	3.8 (2.8-5.6)	knee injury and osteoarthritic score 120.3 ± 40.8 with 29.8% with a poor KOOS (<114)
Takeuchi et al[69]	16 (LCW)	68 (58-73)	8 (4-10)	HSS knee score 91 at f/u
Terauchi et al[70]	37 (dome osteotomy)	66 (46-76)	7.4 (5-10.5)	HSS knee score 84 w/3.7% TKA
Christodoulou et al[71]	32 (LCW)	58	5	Knee society score group A and B combined 96.7% excellent results (2 TKA), group A 80 ± 3.67
	32 (LCW with lateral retinacular release)	56	5	knee society score group B 91 ± 2
Marti et al[72]	34 (lateral opening wedge)	43 (17-66)	11 (5-21)	Lysholm and Gillquist scale 26% excellent, 62% good, 12% fair/poor
Saito et al[73]	73 (LCW)	64 (47-83)	avg 4.83 (2-9.9)	Knee Society score 94 and function score 92
Letloff et al[74]	71	Avg 10 (5.8-16.8)	38 (17-73)	Insall 83% good

MOW – medial opening wedge; LCW – lateral closing wedge

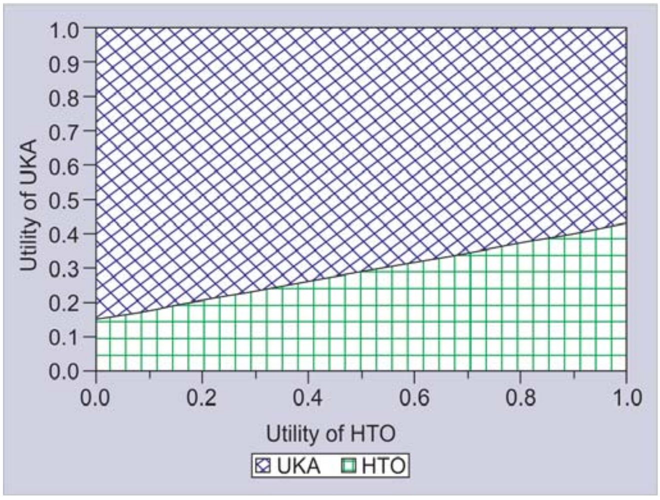

Fig. 3: The treatment decision that results for patient by varying the utility of HTO and UKA. Above the curve UKA is the more effective strategy while below the curve HTO is preferred.

institution, patients undergoing HTO commonly undergo simultaneous arthroscopy and chondroplasty. As such, we choose to include reimbursement data reflective of these CPT modifiers. Table 1 represents the respective cost of the procedures with their ranges used in this analysis.

Cost-Effectiveness Analysis

The Markov model was used to conduct a cost-effectiveness analysis of the base case parameters. The present-day value of the expected costs and QALYs gained over the lifetime of a theoretical patient cohort were calculated based on treatment strategy. Reported outcome measures included average costs and effectiveness (QALYs) as well as the cost-effectiveness (C/E) ratio for each strategy. The incremental costs and effectiveness were also calculated and represent the relative difference between the two alternative strategies. The principle outcome measurement calculated was the incremental cost-effectiveness ratio (ICER), which is the ratio between the difference in costs and difference in QALY of each strategy. In terms of this model, the ICER could be expressed as ICER = $(\text{Cost}_{UKA} - \text{Cost}_{HTO})/(\text{QALYs}_{UKA} - \text{QALYs}_{HTO})$. ICERs less than $50,000 per QALY gained were considered to be cost-effective based on a willingness of the health-care system to pay (WTP) value of $50,000. In this cost-effectiveness analysis, the preferred treatment strategy was the most effective strategy with an ICER < WTP. Lastly, a Monte Carlo microsimulation was conducted to establish confidence intervals for the results of outcome measures from base case analysis (Table 4).

Sensitivity Analysis

Sensitivity analyses were used to validate the model to determine the impact of input variables across their range of reasonable values. This is done to assess the effect that each variable has on the outcome of the model. If changing a variable changes the preferred strategy (i.e. the most cost-effective strategy), then the model is deemed “sensitive” to that variable, if not then it is “robust”. One-way sensitivity analyses, which change the value of a single variable at a time, were performed on the age of the cohort, all costs, utilities and probabilities used in the model. Any input variable capable of significantly influencing the ICER or altering the preferred treatment method is reported in the results. To further validate the base case findings, variables were subjected to multivariate sensitivity analyses by varying the value of more than one variable at a time.

RESULTS

In the base case analysis, the average cost of HTO was an added $842 (2339 to +2746) when compared to UKA. UKA resulted in a significant incremental effectiveness gain compared to HTO of 0.96 QALY. On average, UKA gained 20.05 (5.98 to 24.91) QALY at a cost-effectiveness (C/E) ratio of $1276 (466 to 2941) QALY, whereas HTO gained 19.09 (5.74 to 23.97) QALY at a C/E ratio of $1214 (1614 to 2875)/QALY (Table 4).

The incremental cost-effectiveness ratio (ICER), which is the ratio between the difference in costs and difference in QALY of each strategy ICER = $(\text{Cost}_{UKA} - \text{Cost}_{HTO})/(\text{QALYs}_{UKA} - \text{QALYs}_{HTO})$ was calculated as $877 ICERs less than $50,000 per QALY gained are considered to be cost-effective based on a willingness of the health care system to pay (WTP) value of $50,000. In this cost-effectiveness analysis, the preferred treatment strategy was the most effective strategy with an ICER < WTP or rather the UKA.

Although, the literature reports better survivorship for UKA when compared to HTO, uncertainty exists in younger, more active patients who may subject the prosthesis to a greater demand leading to increased wear and potentially implant failure. A sensitivity analysis was used to evaluate the effects of this uncertainty by varying the underlying assumption for the durability of unicompartmental knee replacements. We compared the relative risk of failure of UKA to the utility of HTO to determine any changes to the cost-effectiveness ratio. The cost-effectiveness of UKA is not lost despite the effects of

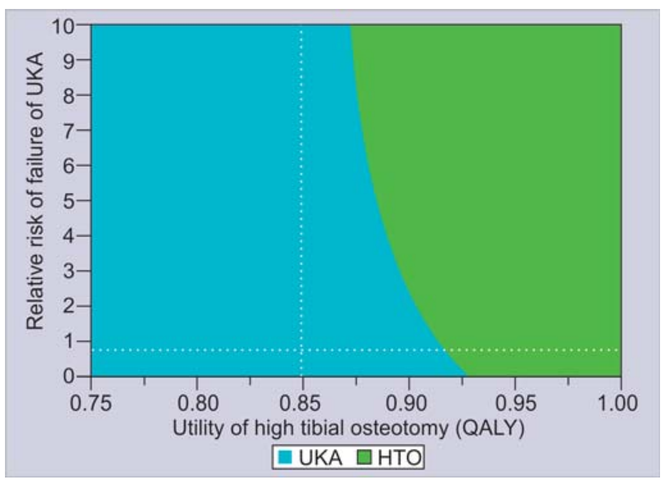

Fig. 4: The treatment decision that results for active patient by varying the utility of HTO and failure rate of UKA. Left of the curve UKA is the more effective strategy while to the right HTO is preferred.

Table 4: Results of the cost-effectiveness analysis for the base case

Strategy	*Avg cost*	*95% CI*	*Incremental cost*	*95% CI*	*Average effectiveness*	*95% CI*	*Incremental effectiveness*	*C/E ratio*	*95% CI*
HTO	$21,855	$9,241-41,961	+$842	—$2,339-(+)2,746	19.09 QALYs	5.74-23.97		$1,214/QALY	$1,614-2,875
UKA	$21,013	$15,041-41,102			20.05 QALYs	5.98-24.97	0.96 QALY	$1,276/QALY	$466-2,941

C/E – cost-effectiveness; ICER – incremental cost-effectiveness ratio

Table 5: Difference in total knee revisions avoided and potential cost savings

Events	*TKA revision*	*TKA revision avoided*	*Cost savings*
HTO	38,490	—	—
UKA	20,782	17,708	$331,635,424

durability or increasing wear of the implant (Fig. 1). In the best case scenario, when HTO and UKA have equal utilities, HTO is the preferred strategy until HTO failure rates reach twice that found in the literature. However, if the utility of HTO is less than UKA at 0.85 even with a predicted failure rate 10 times that used in this model, the preferred strategy will be UKA. The variable utility of HTO was compared to the utility of UKA in a two way sensitivity analysis (Fig. 3). Only when the utility of HTO is greater than UKA does the preferred strategy change to HTO. The utility of HTO would have to be significantly greater than UKA to an extent that is not supported by the literature before HTO could realize a greater net health benefit.

In our Monte Carlo simulation, we were able to show how many events are avoided by choosing UKA over HTO. By choosing HTO over UKA, patients enter the TKA health state earlier which equates to more patients needing knee revisions. The Monte Carlo simulation showed that the number of TKA revision avoided per 100,000 patients is 17,708 with approximate cost savings of $331,635,424, if we set the average cost per TKA revision at $18,728. Table 5 shows the number of events avoided as well as surgical failures.

DISCUSSION

The best treatment for a patient with unicompartmental osteoarthritis in the knee has been debated extensively. Methods of managing this include conservative management, arthroscopy, HTO, UKA and TKA. We choose to compare the cost-effectiveness of unicompartmental arthroplasty to that of high tibial osteotomy. Factors, such as disease distribution, age and patient activity level, have been discussed to play a role in deciding to choose treating a patient with a high tibial osteotomy or unicompartmental arthroplasty. This is the first study to examine the cost-effectiveness of UKA and HTO.

The uncertainty in this model arises primarily from the assignment of utility values. While one can disagree about the specific base case utility values, the literature, devoid of strong level I quality of life outcome data, does suggest the utility of UKA may be greater than HTO. Most authors discuss their results of either HTO or UKA, but only a few publications deal with direct comparison of the clinical results of both procedures. Broughton and Newman et al[39] reported a comparative retrospective study of UKA (42 knees) and HTO (49 knee) after 5 to 10 year f/u with UKA 76% good to excellent, 10% fair, 7% poor and 7% revisions (mean 2.7 years). Results for HTO were 43% good, 22% fair and 6% poor with 20% revised to TKA (mean 4.4 years). Stukenborg Colsman et al[7] reported a randomized, prospective study of 62 patients undergoing either UKA or HTO. A Kaplan-Meier survival analysis in this report showed a survivorship of 77% for UKA and of 60% for HTO, with a higher rate of intraoperative and postoperative complications in the HTO. Sprenger and Doerzbacher et al[6] reported survival rates for tibial osteotomy in 66 patients at a mean of 69 years of age approached 74%, 70% and 65% at 5, 10 and 15 years respectively.[47] Prior published results are consistent with those reports on HTO in that it produces satisfactory early results but they tend to deteriorate with time. To account for this decline we used a variable utility value for HTO (Table 2). Sensitivity analysis of our model revealed one critical conclusion regarding utility and cost-effectiveness. If the utility of UKA is greater than or equal to HTO, UKA is a dominant treatment strategy compared to HTO. Since there were no published studies in our literature review that suggested HTO could have greater utility than UKA, we believe that this is unlikely and UKA is the preferred strategy.

There are several limitations to this study. First, we do not account for differences in surgeon experience on outcomes. UKA has been proposed as a more technically demanding procedure.[7,31] The majority of the failure rates and outcome measures used to create our analysis came from higher-volume centers. Therefore, these results may not be extrapolated to all cases of unicompartmental arthritis in other health systems. Still, UKA failure can rise by a factor of 10 with little change in the preferred strategy if the utility of UKA is greater than HTO (Fig. 3).

Secondly, this study only evaluates unicompartmental osteoarthritis in patients aged 40 and older. There is a high incidence of medial compartmental osteoarthritis in active patients for whom arthroplasty is an imperfect solution. Treatment of this disease in younger, higher demand patients is met with different challenges.[2] Outcomes and failure rates may be different than those used in this study. Although vulnerable to wear and loosening, good long-term survivorship has been reported in recent studies for UKA.[48] Important causes of long-term failure of UKAs include wear, loosening and adjacent compartment degeneration. Price and Dodd et al[49] reported on the results of the Oxford unicompartmental knee arthroplasty in patients younger than and older than 60 years of age. The 10-year all-cause survival of the < 60 years of age group (52) was 91%, while in the ≥ 60 years of age group (512), the figure was 96%.[49] Analysis of 1,135 revised UKAs from the Swedish registry indicated that the primary reason for revision was component loosening (43% of cases) followed by progression of adjacent compartment arthritis (26%) and other mechanical problems (15%).[31] During sensitivity analyses, we found that the cost-effectiveness of UKA continues despite the effects of durability or increasing wear of the implant. Assuming more active patients may have a higher relative risk of failure does not seem to affect the cost-effectiveness (Fig. 4). Like most operations more selective criteria for use of either HTO or UKA are likely to provide superior clinical outcomes.

UKAs have been reported to have a shorter time to full weight bearing, easier rehabilitation and fewer perioperative complications.[7,39,40] When healed, however, HTO does not impose any activity restriction where as arthroplasty mandate activity modification due to concern about wear and durability. Isolated unicompartmental disease in a physiologically young, high-demand individual is thought to favor HTO. Some report that HTO may temporarily alter the natural history of the underlying osteoarthritis. Odenbring and Egund et al[50] detected fibrocartilage proliferation in and increased cellularity of hyaline cartilage after HTO. In addition, mechanical alignment correction allows the possibility of evolving chondral resurfacing techniques which may provide improved results.[51] With this in mind, preservation of bone stock and intra-articular structures are major advantages of HTO.

HTO's average cost was $842 higher than UKAs. Both of these procedures are cost-effective with the cost-effectiveness (C/E) ratio of UKA being $1048/QALY and HTO being $1145/QALY. The relative costs of HTO, UKA and total knee arthroplasty are also key variables that could impact the potential cost-effectiveness gains of UKA. The gross-costing methods used in this study may not provide as precise an estimate of costs as would more detailed micro-costing techniques.[15] While Medicare reimbursement may overestimate or underestimate the actual costs of care, the cost estimates derived from this method for the present study are in the range of previously published estimates of the cost of UKA, primary and revision total knee arthroplasty derived from other studies.[3,52,53] There are no prior reports on the cost of HTO combined with chondroplasty for comparison in the literature. The effect of the uncertainty about the cost variables was examined with use of sensitivity analysis and did not lead to a change in the dominant strategy being UKA.

UKA resulted in a significant incremental effectiveness gain compared to HTO of 0.96 QALY. The applicability of these findings must also be guided by an understanding of the assumptions used in this study. The reference case assumes a patient age of 40 years. However, in many instances, a UKA is implanted in patients who are older. The literature not only demonstrates a high rate of survival for UKA in our aged population but also reports guarded results when implanting in a younger active patient. [4,54-56] Therefore, many advocate for the use of HTO in younger patients. While UKA resulted in a significant incremental effectiveness gain compared to HTO of 0.96 QALY in our cohort, the applicability of these findings may not extrapolate to a younger cohort. Additional analysis would be helpful if better selection criteria are used for the treatment of unicompartmental OA.

CONCLUSION

Both UKA and HTO are cost-effective procedures but UKA is the cheaper strategy. Markov modeling suggests patients treated with UKA may experience an increased net health benefit over their lifetime. This model support the use of UKA over HTO for the treatment of unicompartmental osteoarthritis in patients 40 years and older. However, with improved selection criteria with regard to disease distribution, age, patient activity and with potential new advances in chondral techniques future cost-effectiveness of these two strategies may change.

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