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The cost-effectiveness of computer navigation in primary total knee replacement: a scoping review

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- Despite additional costs associated with the use of computer navigation technology in total knee replacement (TKR), its impact on quality-adjusted life years following surgery has not been demonstrated. Cost-effectiveness evaluations require a balanced assessment of both quality and cost metrics.
- This review sought to evaluate the cost-effectiveness of computer navigation, identify barriers to translation, and suggest directions for further investigation. A systematic search of the Cost-Effectiveness Analysis Registry, PubMed, and Embase was undertaken.
- Cost-effectiveness analyses of computer navigation in primary total knee replacement were identified. Only primary studies of cost-effectiveness analyses published in the English language from the year 2000 onwards were included. Studies that reported secondary data were excluded from the analysis. Four publications met the inclusion criteria.
- Estimated gains in quality-adjusted life years attributed to reductions in revision surgery were 0.0148 to 0.0164 over 10 years, and 0.0192 (95% CI –0.002 to 0.0473) over 15 years. Cost estimates ranged from 952 kr (US $90, 2020) per case at 250 TKRs/year, to $1,920 US per case at 25 TKRs/year.
- The estimated probability of meeting local cost-effectiveness thresholds was 54% in the United States and 92% in the United Kingdom. These data were not available for Norway.
- The cost-effectiveness of computer navigation in current practice settings remains uncertain, with the use of this technology associated with marginal increased quality-adjusted life years (QALYs) at additional cost. Existing analyses demonstrated a number of limitations which restrict the potential for translation to practice and policy settings. Further research evaluating the impact of computer navigation on QALYs following primary TKR is required to inform contemporary cost-effectiveness evaluations.

Keywords: computer assisted surgery; computer navigation; cost-effectiveness; total knee arthroplasty; total knee replacement

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Introduction

The growing burden of knee osteoarthritis presents a significant challenge facing many communities.[1] Total knee replacement (TKR) remains the only definitive treatment option available for advanced arthritis, and this has seen its use continue to increase across a number of countries.[2] It is also a high-cost procedure with a well-documented complication profile.[3,4] Efforts to improve outcomes and minimize complications following surgery have driven the research and development of a range of innovative assistive technologies.[5] The use of computer navigation technology enables precise control over prosthesis alignment, with neutral alignment thought to result in superior patient outcomes and reduce the risk of revision surgery.[6] Early improvements in pain and function have been reported, along with higher prosthesis survival for patients < 65 years of age.[7–9] There remains uncertainty as to whether the use of computer navigation translates to improvements in quality-adjusted life years (QALYs), a quality metric employed in cost-effectiveness analyses which measures preferences for certain health states over time.[10]

The potential for advanced health technologies to improve a range of outcome measures has led to their increasing use in surgery.[5] The growing cost burden resulting from this trend has raised concerns about their impact on health budgets which are constrained by scarce funding.[3,11] Due to competing demands from high-cost interventions, there is now a greater focus on delivering value in healthcare.[12,13] Determining value requires a balanced assessment of both quality and cost metrics to inform cost-effectiveness valuations. The value-based assessment of healthcare interventions has an important function in assisting policymakers with the allocation of limited health budget resources towards interventions that are clinically effective but also cost-effective.[14] There is a shared responsibility to meet community expectations and ensure that additional costs incurred with the use of high-cost healthcare interventions are justified by their delivery of improved health outcomes.

The cost-effectiveness of TKR has been well investigated in the setting of its increased utilization.[15] However, there have been no comparable reviews evaluating the cost-effectiveness of computer navigation despite its increasing adoption in TKR.[16] Although there is inadequate evidence to suggest whether computer navigated TKR offers incremental gains in QALYs, its use incurs additional costs.[6] We therefore performed a scoping review to evaluate the cost-effectiveness of computer navigation in primary TKR. There were three aims: (1) to evaluate published economic analyses assessing the cost-effectiveness of computer navigation in TKR, (2) to identify limitations that exist within existing analyses, and (3) to suggest directions for further research that can clarify and further inform the valuation of computer navigation in TKR.

Methods

This scoping review was conducted according to Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) guidelines.[17] Publications were eligible for screening if they met the following criteria: (1) English language, (2) full text, and (3) publication date of 2000 or subsequent year. Full-text publications were required to enable an analysis of the economic modelling, and a publication date of 2000 or subsequent year was arbitrarily chosen to reflect the timeline of computer navigation adoption. PubMed and Embase were searched using the following strategy: “((total knee replacement) OR (total knee arthroplasty)) AND ((computer navi*) OR (computer assist*)) AND (cost effectiveness)”. The Cost-Effectiveness Analysis Registry was searched using the terms “total knee replacement”, “total knee arthroplasty”, “computer navigation”, and “computer assistance”. The CEA Registry is a collection of English-language publications which use QALYs as part of the cost-effectiveness analysis, and is hosted by the Center for the Evaluation of Value and Risk in Health at Tufts University.[18] Results from the search strategy underwent title and abstract screening and were included following full-text review if the study was primary research evaluating the cost-effectiveness of computer navigation in primary total knee replacement. Studies presenting secondary data (reporting results from separately performed primary research) were excluded. The following study characteristics were extracted into Microsoft Excel 2016 (Microsoft, Washington, United States): year of publication, country, study design, payer perspective, patient population, modelling parameters relating to measures of cost and effectiveness, sensitivity analyses, discounting rates, cost-effectiveness thresholds, and summary of cost-effectiveness.

Results

Search strategy

The results are illustrated in the PRISMA flow diagram (Fig. 1). A total of four cost-effectiveness analyses met eligibility for inclusion.

Study characteristics

The data abstraction is presented in Table 1. All studies simulated scenarios over a fixed number of monthly or yearly cycles; none were performed as observational or clinical trials. Modelling was performed using a range of values under sensitivity analyses, and cost-effectiveness was estimated using input data from both published literature and estimates. The payer perspective adopted was universally that of the healthcare system, in contrast to the societal perspective which also includes costs incurred outside of the healthcare system.[19] All studies nominated a locally applicable cost-effectiveness threshold against which scenarios were compared to determine cost-effectiveness. There were a total of four cost analyses: two studies presented the probabilities of achieving cost-effectiveness across the scenarios in their modelling, and two studies presented suggested reductions in the rate of revision surgery required to achieve cost-effectiveness.[20–23]

Effectiveness of computer navigation

Effectiveness was measured using QALYs.[10] QALYs are calculated by adjusting utility values for survival time.[24] Utility values are a single index that represents preferences for different states of health, ranging on a scale from 0 (death) to 1 (full health), and are typically derived from health-related quality of life scores of questionnaires such as the Short-Form 6 Dimension (SF-6D) and EuroQol 5 Dimension (EQ-5D).[25] Each of the four studies derived utility values from either the SF-6D or the EQ-5D, and these data are presented in Table 1.

Across the included studies, the cumulative QALY gain following TKR was determined by adding the utility value at each cycle over the full cycle. The cycles started from a pre-operative state of knee arthritis, progressed to primary TKR following either navigated or non-navigated arms, and then various states of transition were modelled

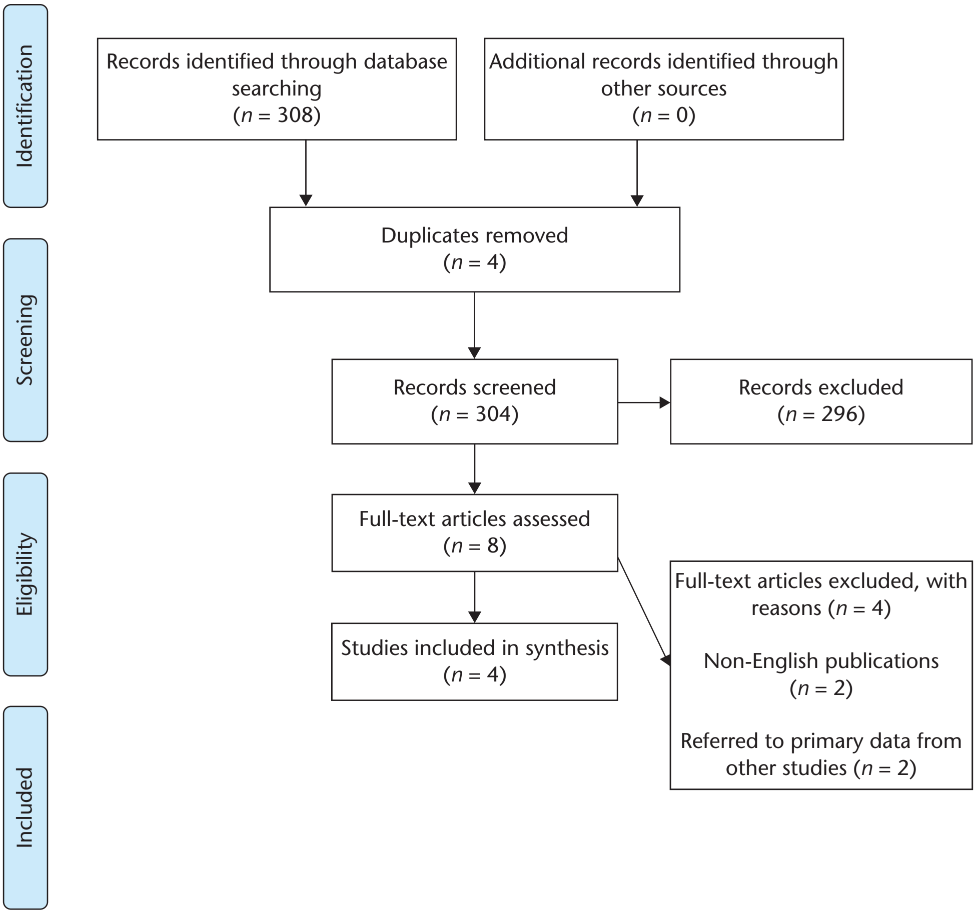

Fig. 1 PRISMA flow diagram.

including neutral alignment/malalignment, complications, revision TKR, and death. The utility value for each state, survival from revision, and probabilities of transitioning across each state during the cycle were derived from existing arthroplasty literature, the Swedish and Norwegian arthroplasty registries, and United States Medicare cohort data. No differences in the TKR utility values between the navigated and non-navigated arms were modelled in the analyses. The impact of computer navigation on QALYs was primarily due to reductions in the state of malalignment and reductions in transitioning to a revised TKR state. Death with an unrevised TKR resulted in a higher cumulative lifetime QALY gain compared to death after transitioning to a revised TKR state. Navigated TKR, with reductions in malalignment and hence a reduced probability of transitioning to the revised state, therefore resulted in higher cumulative lifetime QALYs.

Utility values attributed to the primary TKR across the four analyses ranged from 0.73 to 0.92 QALYs (with sensitivity analysis values ranging from 0.00026 to 1). Utility values attributed to revision TKR ranged from 0.51 to 0.80 QALYs (0 to 0.99997). Two studies factored in a disutility value for the first year following primary TKR (–0.10 QALYs) or revision TKR (–0.20 QALYs), which is a reduction in the utility value for the first year due to the recovery period following surgery prior to attaining a steady-state utility value.[22,23] A number of other transitional states between primary TKR in a 'normal' state of health and 'complex' revision TKR were included as transition states.

The use of computer navigation was estimated to increase QALYs by 0.0192 (95% CI –0.002 to 0.0473) in the United States over a 15-year cycle, and by between 0.0148 to 0.0164 QALYs in the United Kingdom over a 10-year cycle.[20,21]

Cost of computer navigation

Costs in the four studies referred to the price paid for purchasing the navigation system and associated expenses, with one study also pricing the additional consumption of resources related to extra operating time required for use of computer navigation (Table 1).[20] The cost of purchasing equipment (system, software, maintenance, disposables) was typically obtained from the hospital purchasing department or vendors. Upfront costs of purchasing the

Table 1. Data abstraction of economic modelling analyses evaluating the cost-effectiveness of computer navigation in total knee replacement.

Author	**Dong and Buxton**[20]	**Novak et al**[21]	**Slover et al**[22]	**Gøthesen et al**[23]
Journal	*International Journal of Technology Assessment in Health Care*	*Journal of Bone & Joint Surgery*	*Journal of Bone & Joint Surgery*	*BMC Musculoskeletal Disorders*
Year	2006	2007	2008	2013
Country	United Kingdom	United States	United States	Norway
Design	Markov model	Markov model	Markov model	Markov model
Period	120 monthly cycles	15 yearly cycles (sensitivity 5–15 yearly cycles)	20 yearly cycles	20 yearly cycles
Study type	Cost-effectiveness analysis	Cost-effectiveness analysis	Cost-effectiveness analysis	Cost-effectiveness analysis
Unit of effectiveness	Quality-adjusted life years	Quality-adjusted life years	Quality-adjusted life years	Quality-adjusted life years
Unit of cost	2003 GBP	2006 USD	2007 USD	NOK (year not stated)
Perspective	Healthcare system	Healthcare system	Healthcare system	Healthcare system
Population	Not stated	Individuals undergoing primary TKR for osteoarthritis	5% sample of Medicare TKR recipients from 1997–2004 (age ⩾ 65 years)	60- and 75-year-old individuals
Model parameter (effectiveness)	Utility values Source: published literature and estimations Pre-operative: N/A Post-operative primary: 0.72 QALY (0.00026 to 1) Post-operative primary with normal health: 0.78 QALY (0.00026 to 1) Post-operative primary with minor complications: 0.66 QALY (0 to 1) Post-operative primary with major complications: 0.35 QALY (0 to 0.79542) Post-operative revision (simple): 0.66 QALY (0.00076 to 1) Post-operative revision (complex): 0.51 QALY (0 to 0.99997) 10 year revision Conventional TKR: simple (2.6%), complex (5.1%) Navigated TKR: simple (1.9%), complex (3.6%) Effect of CAS assumed to be reduction in transition to 'TKR with serious complication': CAS reduces malalignment by 48%, malalignment responsible for 70.4% of complications, CAS therefore reduces serious complications by 34%	Utility values Source: published literature Pre-operative primary: N/A Post-operative primary: 0.92 QALY (sensitivity 0.82 to 1) Post-operative revision: 0.80 QALY (sensitivity 0.60 to 0.90) Total disutility primary: N/A Total disutility revision: N/A Revision Source: published literature, weighted mean by number of patients included in each study, range of follow-up 2 months to 15 years Neutral alignment Years 0–5: 0% per year Years 6–15: linear rate, cumulative 4.7% at 15 years Malaligned: Years 0–9: cumulative 7% at 9 years Years 10–15: cumulative 54% at 15 years	Utility values Source: Swedish Hip Arthroplasty Registry Pre-operative: 0.40 QALY Post-operative primary: 0.75 QALY Post-operative revision: 0.60 QALY Total disutility primary: –0.10 QALY Total disutility revision: –0.20 QALY Revision Source: 5% sample of Medicare cohort from 1997 to 2004 (aged ⩾ 65 years) Years 1–8: linear rate equal to Medicare population Years 9–13: 0.8% per year Years 14–20: 1.0% per year Cumulative revision rate at 20 years consistent with the Swedish National Hip Arthroplasty Registry	Utility values Source: Swedish Hip Arthroplasty Registry and published literature Pre-operative: 0.40 QALY Post-operative primary: 0.73 QALY Post-operative revision: 0.60 QALY Total disutility primary: –0.10 QALY Total disutility revision: –0.20 QALY Revision Source: Norwegian Arthroplasty Registry Years 1–11: annual rate determined by Kaplan-Meier analysis Years 12–20: annual rate determined to match Swedish Knee Arthroplasty Registry and cohort studies at 20 years Patients aged 60 years: revision rate for cohorts < 70 years Patients aged 75 years: revision rate for cohorts ⩾ 70 years
Malalignment definition	Exceeding 3 degrees from mechanical axis (one study) Exceeding 0 degrees from mechanical axis (two studies)	Exceeding 3 degrees from mechanical axis	Not defined	Not defined
Model parameter (cost)	TKR Source: NHS Reference Costs 2003 Healthcare Resource Group H04 (primary): £5,197 (sensitivity £4,218 to £6,217) Simple revision: £6,234 (sensitivity £5,043 to £7,972) Complex revision: £7,326 (sensitivity £5,086 to £11,307) Other treatment: £2,844 (sensitivity £1,428 to £5,579) Computer navigation Source: not stated Navigation system: not stated Software: not stated Maintenance: not stated Amortization: 5 years Cost per case: estimated £235 at 250 cases/year (inclusive of system, warranty, disposables, additional operating time)	TKR Source: 2006 Medicare reimbursement Diagnosis Related Group 544 (primary): $11,018 (sensitivity $8,000 to $20,000) Diagnosis Related Group 545 (revision): $13,922 (sensitivity $10,000 to $30,000) Computer navigation Source: Published industry sources, 8 vendors representing 5 computer navigation equipment manufacturers Navigation system: not stated Software: not stated Maintenance: not stated Amortization: not stated Cost per case: $1,500 baseline estimate (sensitivity $650 to $4,000)	TKR Source: Massachusetts General Hospital billing department Diagnosis Related Group 544 (primary): $15,574 Diagnosis Related Group 545 (revision): $20,728 Computer navigation Source: Massachusetts General Hospital purchasing department Navigation system: $100,000 Software: $40,000 Maintenance: $20,000 per year Amortization: 5 years at $48,000 per year Cost per case: not stated	TKR Source: not stated Diagnosis Related Group 209A (primary): NOK 146,135 Diagnosis Related Group 209B (revision): NOK 192,418 Computer navigation Source: Brainlab Scandinavia Navigation system: NOK 1,082,500 Amortization: 5 years at NOK 216,500 per year Cost per case: not stated (additional NOK 200 for disposables)
Sensitivity analysis	Yes	Yes	Yes	Yes
Annual discounting	3.5% per year	3% per year (sensitivity 0% to 5%)	3% per year	4% per year
CE threshold	30,000 GBP	50,000 USD	50,000 USD	500,000 NOK
ICER	N/A	45,554 USD	N/A	N/A
Summary	CAS cost-effective Dominant strategy in 75.89% of 10,000 simulations Cost saving in 99.53% of 10,000 simulations 92% cost-effective based on nominated cost-effectiveness threshold	Base case scenario: $1,500 per case; net QALY gain of 0.019 and net additional cost of $871 USD with an ICER of $45,554/QALY. Cost-effective at threshold of $100,000/QALY by 12.13 years, and at $50,000/QALY by 14.56 years. Across 1,000 simulations in the sensitivity analysis, 54% ICER < $50,000/QALY and 74% ICER < $100,000/QALY	At the CE threshold of 50,000 USD, relative reductions in the rate of revision surgery over a 20-year period are required at a cost of 48,000 USD per year for the following annual case volumes: 25/year: 13% reduction 150/year: 2.5% reduction 250/year: 2% reduction	Over a 20-year cycle, assuming only additional costs incurred and no change in outcomes from navigation: QALY gain: 7.44 (60 yrs) and 5.46 (75 yrs) Additional costs: 25 cases/year: NOK 1,037 (60 yrs), NOK 1,414 (75 yrs) 250 cases/year: NOK 128 (60 yrs), NOK 175 (75 yrs) To meet CE threshold, relative reduction in rate of revision at 10 years required: 25 cases/year: 7.5% (60 yrs), 7% (75 yrs) 250 cases/year: 1% (60 yrs), 1% (75 yrs)

(continued)

Table 1. (Continued)

Author	**Dong and Buxton**[20]	**Novak et al**[21]	**Slover et al**[22]	**Gøthesen et al**[23]
Limitations	Serious complication not defined or described Wide variation in range of estimated utilities used in sensitivity analysis due to lack of data, not necessarily reflect of realistic scenario	Inconsistencies in figures reported (4.7% vs. 4.8% cumulative revision to 15 years for neutral alignment, reporting of years 5–15 vs. years 6–15)	Estimates of transition probabilities – historical data which may vary between different volume centres, does not account for losses in HRQOL prior to revision, assumption that no re-revisions were required, did not factor indirect costs, cost estimates are for local situation	Misleading as 60-year-old cohort represents revision rate for under 70s, and 75-year-old cohort represents revision rate for ⩾ 70s. Does not account for direct costs of additional operating time Utility values are historical and extrapolated from literature
Sensitivity analysis	Deterministic and probabilistic One-way: utility	Probabilistic One-way: alignment, utility, cost, discount rate, follow-up duration	Deterministic Two-way: hospital volume, annual cost of computer navigation, revision rate, cost-effectiveness of computer navigation	Deterministic Two-way: patient volume, probability of revision, cost-effectiveness of computer navigation, age cohorts

Note. TKR, total knee replacement; QALY, quality-adjusted life year; CAS, computer assisted surgery; CE, cost-effectiveness; ICER, incremental cost-effectiveness ratio; HRQOL, health-related quality of life.

computer navigation system were averaged over a five-year useable lifespan. Discounting rates of 0% to 5% per year were factored into the modelling to account for the impact of inflation over time. The included studies did not evaluate costs associated with prostheses or training.

For an annual procedural volume of 250 TKRs, the average additional cost per case was estimated at US$192 in the United States, £235 (US$292, 2020) in the United Kingdom, and 952 kr (US$90, 2020) in Norway. At 25 TKRs per year, this was estimated at US$1,920 per case in the United States, and 1,037–1,414 kr (US$98-133, 2020) for 60-year-old patients and 75-year-old patients respectively in Norway.

One analysis in the United States estimated that cost savings could be achieved if the additional cost per case was < US$629, due to reductions in the number of higher-cost revision TKRs over a 15-year cycle of care.[21] A British analysis estimated that in some scenarios cost savings of £583 to £637 (US$727 to US$795, 2020) per case could be achieved over a 10-year cycle of care.[20]

Cost-effectiveness of computer navigation

The QALY gains from computer navigation, at an additional cost of US$1,500, resulted in an incremental cost-effectiveness ratio of $45,554/QALY in the United States; 54% of simulations were cost-effective below the local threshold of US$50,000.[21] In the United Kingdom, computer navigation was suggested to be more effective and less costly in greater than 75% of simulations, with a 92% probability of achieving cost-effectiveness at a £30,000 threshold.[20] Two studies proposed that reductions in the rate of revision surgery were required to attain cost-effective outcomes (Table 1).[22,23] This requirement ranged from relative reductions of 13.0% at a case volume of 25 TKRs/year to 2.0% at case volumes of 250 TKRs/year in the United States.[22] In Norway, the required reductions were 7.0% (75-year-old cohort) and 7.5% (60-year-old cohort) at 25 TKR/year case volume to 1.0% for both age cohorts at 250 TKR/year case volume.[23] With larger case volumes, smaller reductions in the percentage of patients transitioning to the revised state and its associated lower utility value were required to achieve QALY gains sufficient to offset the increased costs of computer navigation.

Discussion

The cost-effectiveness of computer navigation in primary TKR

This review was performed to evaluate the cost-effectiveness of computer navigation in TKR. Computer navigation has not been demonstrated to be a clearly dominant (more effective and less costly) nor dominated (less effective and more costly) strategy; included studies suggested the use of this technology is associated with marginal additional QALYs at additional cost.

Markov analysis was used to model transitions across a range of health states to estimate the cost-effectiveness of computer navigation in primary TKR.[20–23] Cost-effectiveness analysis requires a balanced assessment of both cost and effectiveness, summarized as an incremental cost-effectiveness ratio (ICER) which is the cost of attaining an additional QALY (Fig. 2). ICERs are compared to a nominated cost-effectiveness threshold, with interventions whose ICERs fall below this threshold deemed cost-effective and those that lie above deemed not cost-effective.

$$\text{ICER} = (\text{cost of intervention} - \text{Cost of comparator}) / (\text{QALY of intervention} - \text{QALY of comparator})$$

Fig. 2 Formula for the incremental cost-effectiveness ratio (ICER).

Note. QALY, quality-adjusted life year.

The use of ICERs aids decision analysis for interventions that improve QALYs at additional cost, as this requires a trade-off between improved health outcomes but greater investment of scarce health resources. Interventions that both improve QALYs and reduce costs are deemed 'dominant', and those that both reduce QALYs and incur greater costs are in contrast considered 'dominated' strategies.[26]

It remains unclear whether the use of computer navigation in TKR is cost-effective due to variation in underlying assumptions and transition states. The cost-effectiveness of TKR has been extensively evaluated under a range of settings, with a number of outcomes and cost drivers reported.[27,28] By comparison, the investigation of the cost-effectiveness of computer navigation in primary TKR has been limited. There may be a role for its targeted adoption if clear evidence of improvements in quality-adjusted life years and reductions in the rate of revision surgery can be demonstrated at an appropriate cost. The widespread adoption of newer technologies prior to evidence of benefit may shift limited healthcare resources towards lower-value care.[29] The value analysis of computer navigation is particularly important due to the increasing use of high-cost healthcare technologies which are widely recognized as a significant cost driver of healthcare expenditure.[30]

Limitations to practice and policy translation

It has been recognized that numerous studies may be underpowered to unmask potentially small but significant differences in outcomes within certain patient cohorts.[31] This is particularly worth noting as the reported QALY gains from computer navigation have been fairly small relative to the range of utility values assumed or estimated in the modelling scenarios. There was a large degree of variation in the utility values assigned to the same health states by different authors, and this was largely a reflection of the broader published literature as stated Gøthesen et al.[23] Dong and Buxton in their study assigned utility values to certain health states based on assumptions due to a lack of published data.[20] Similarly, utility values from total hip replacement cohorts were adopted for total knee replacement cohorts by Gøthesen et al and Slover et al.[22,23] Whilst hip and knee replacements are both arthroplasties of large lower extremity joints, they are distinct procedures and differences in utility values have been reported by Konopka et al.[32] Further to this, Schilling et al have demonstrated the impact of timing on utility values and QALYs that are subsequently derived from health-related quality of life scores.[33] These limitations indicate that even relatively minor changes in the underlying assumptions, and differences in underlying assumptions, may be sufficient to affect the interpretation of the outcomes reported by the modelling despite sensitivity analyses. The underlying assumptions will need to be revisited and further investigated as new data come to light with longer-term follow-up now available.

The effectiveness of computer navigation was generally attributed to reductions in the rate of revision surgery as a result of reductions in the proportion of malaligned TKRs. Two analyses estimated reductions in the rate of revision surgery that were required to meet nominated cost-effectiveness thresholds for a range of surgical volumes ranging from 25 to 250 TKRs/year.[22,23] However, malalignment is the underlying aetiology for only a proportion of revision TKRs.[34] The effectiveness of computer navigation as measured by reductions in the rate of revision surgery has largely not been borne out by the literature, with limited exceptions.[7] Revision rates were derived from a diverse range of sources and based on survival data from surgeries performed in previous decades. With advancements in technique and technology, any narrowing of potential differences in survival between mechanical and computer navigated TKR may have implications for the interpretation of existing cost-effectiveness analyses. It remains unclear whether the proposed reductions in revision surgery are feasible, particularly in lower-volume settings where the required reduction is considerably greater compared to higher-volume settings.

The analyses suggested that the additional cost of computer navigation for each case decreased in association with higher surgical volumes. Lower-volume hospitals operated at a higher unit cost due to the significant capital investment required to procure a computer navigation system.[35] Lower-volume hospitals also had a lower likelihood of meeting nominated cost-effectiveness thresholds as a result of these higher costs.[22] Despite this, the benefits of computer navigation were considered more likely to be realised in lower-volume hospitals due to the possibility of mitigating poorer outcomes. The literature has reported associations between lower hospital volumes and inferior patient outcomes.[35] Further, where the proposed cost-effectiveness of computer navigation is likely improved with higher surgical volumes, the majority of hospitals in the United States do not meet the 250 annual case volume which has informed modelling estimates.[35] In the United States, for example, Katz et al reported that only 25% of TKRs were performed at hospitals with annual case volumes exceeding 200 TKRs.[35] Similar findings may apply to other countries where the use of computer navigation in TKR is also increasingly prevalent.[36] The differences between surgical volumes modelled in the analyses, with direct implications for cost-effectiveness, and the reported surgical volumes undertaken in modern practice settings limits the translation of findings to practice.

Navigating the way forward

The selective use of computer navigation technology has already proven to be advantageous in technically challenging cases where complex deformities or distorted anatomical planes impair the ability to accurately identify landmarks for mechanical referencing. Whilst the definition of accurate alignment is still a matter of active debate, the benefit of computer navigation in enabling greater surgical precision is not disputed.[9] The impact of malaligned prostheses on failure rates is markedly higher in the presence of obesity, defined by the World Health Organization as a body mass index $\geqslant$ 30 kg/m^2.[37] In patients < 65 years old, Australian national registry data demonstrate lower revision rates amongst patients receiving navigated TKRs at 9 years of follow-up.[7] Obese patients represent a significant number of TKR recipients, and patients < 65 years of age represent an increasing proportion of TKR recipients.[38]

Despite the promising benefits in certain patient cohorts, the additional costs incurred and inconsistencies in reported outcomes have encouraged recommendations against universal adoption.[8,9,31] However, a considerable period of time has elapsed since the introduction of computer navigation to TKR. Only in recent years have differences in outcomes and rates of revision surgery started to emerge.[7,39] This offers an opportunity for targeted investigation into the impact of computer navigation on the value and cost-effectiveness of TKR. Computer navigation technology continues to remain an active area of research interest, and long-term follow-up data will help inform future economic decision analyses with a focus on translation to practice and policy settings. This should account for variations in local practice patterns, costs of procuring technologies, and other factors relevant to local cost-effectiveness evaluations. Further research is encouraged to elucidate these differences. The selective use of advanced technology has the potential to improve the cost-effectiveness of surgical practice in an era where the value of high-cost interventions increasingly needs to be justified.

Conclusion

The cost-effectiveness of computer navigation in current practice settings remains uncertain, with the use of this technology associated with marginal increased QALYs at additional cost. Existing analyses demonstrated a number of limitations which restrict the potential for translation to practice and policy settings. Further research evaluating the impact of computer navigation on quality-adjusted life years following primary TKR is required to inform contemporary cost-effectiveness evaluations.

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