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

Cite this article: EFORT Open Rev 2021;6:173-180. DOI: 10.1302/2058-5241.6.200073

**Introduction**

The growing burden of knee osteoarthritis presents a significant challenge facing many communities. 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. It is also a high-cost procedure with a well-documented complication profile. Efforts to improve outcomes and minimize complications following surgery have driven the research and development of a range of innovative assistive technologies. 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. Early improvements in pain and function have been reported, along with higher prosthesis survival for patients < 65 years of age. 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.

The potential for advanced health technologies to improve a range of outcome measures has led to their increasing use in surgery. The growing cost burden resulting from this trend has raised concerns about their impact on health budgets which are constrained by scarce funding. Due to competing demands from high-cost interventions, there is now a greater focus on delivering...
value in healthcare.\textsuperscript{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.\textsuperscript{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.\textsuperscript{15} However, there have been no comparable reviews evaluating the cost-effectiveness of computer navigation despite its increasing adoption in TKR.\textsuperscript{16} Although there is inadequate evidence to suggest whether computer navigated TKR offers incremental gains in QALYs, its use incurs additional costs.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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.\textsuperscript{20–23}

**Effectiveness of computer navigation**

Effectiveness was measured using QALYs.\textsuperscript{10} QALYs are calculated by adjusting utility values for survival time.\textsuperscript{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).\textsuperscript{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.
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

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

| Author            | Year | Country    | Design      | Period        | Study type              | Unit of effectiveness | Unit of cost         | Perspective         | Population | Model parameter (effectiveness) | Model parameter (cost) | Sensitivity analysis | Annual discounting CE threshold | ICER Summary |
|-------------------|------|------------|-------------|---------------|-------------------------|----------------------|----------------------|----------------------|------------|-------------------------------|-----------------------|------------------|--------------------------|------------------|
| Dong and Buxton   | 2006 | United Kingdom | Markov model | 120 monthly cycles | Cost-effectiveness analysis | Quality-adjusted life years | 2003 GBP | Healthcare system | Not stated | Utility values Source: published literature and estimations Pre-operative: N/A | TKR Source: NHS Reference Costs 2003 Healthcare Resource Group H04 (primary): £5,197 (sensitivity £4,217 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) | £3% per year | 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 |
| Novak et al      | 2007 | United States | Markov model | 15 yearly cycles (sensitivity 5–15 yearly cycles) | Cost-effectiveness analysis | Quality-adjusted life years | 2006 USD | Healthcare system | Not stated | Exceeding 3 degrees from mechanical axis (one study) Exceeding 0 degrees from mechanical axis (two studies) | TKR Source: 2006 Medicare reimbursement Diagnosis Related Group S44 (primary): $17,018 (sensitivity $8,000 to $20,000) Diagnosis Related Group S45 (revision): $13,922 (sensitivity $10,000 to $30,000) | £3% per year | $30,000 GBP | N/A | 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 |
| Slover et al     | 2008 | United States | Markov model | 20 yearly cycles | Cost-effectiveness analysis | Quality-adjusted life years | 2007 USD | Healthcare system | 5% sample of Medicare TKR recipients from 1997–2004 (age > 65 yrs) | Not defined | Exceeding 3 degrees from mechanical axis (one study) Exceeding 0 degrees from mechanical axis (two studies) | TKR Source: Massachusetts General Hospital billing Diagnosis Related Group 209A (primary): $15,544 (sensitivity $8,000 to $20,000) Diagnosis Related Group 544 (revision): $20,728 (sensitivity $10,000 to $30,000) | £3% per year | $50,000 USD | N/A | 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 |
| Gøthesen et al   | 2013 | Norway     | Markov model | 20 yearly cycles | Cost-effectiveness analysis | Quality-adjusted life years | Not stated | Healthcare system | NOK (year not stated) | Not defined | Exceeding 3 degrees from mechanical axis (one study) Exceeding 0 degrees from mechanical axis (two studies) | TKR Source: not stated Diagnosis Related Group 209A (primary): NOK 1,082,500 Amortization: 5 years at NOK 216,500 per year Cost per case: not stated (additional NOK 200 for disposables) | £3% per year | $500,000 NOK | N/A | 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 |

(continued)
Cost-effectiveness of computer navigation in TKR

Cost-effectiveness outcomes (Table 1). 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. 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. 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. 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 (ICER) (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.


definition of years 5–15 vs. years 6–15)

utility value were required to achieve QALY gains sufficient to offset the increased costs of computer navigation.

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. 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 \( \geq 30 \text{ kg/m}^2 \). In patients less than 65 years old, Australian national registry data demonstrate lower revision rates amongst patients receiving navigated TKRs at 9 years of follow-up. Obese patients represent a significant number of TKR recipients, and patients less than 65 years of age represent an increasing proportion of TKR recipients.

Despite the promising benefits in certain patient cohorts, the additional costs incurred and inconsistencies in reported outcomes have encouraged recommendations against universal adoption. 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. 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.

AUTHOR INFORMATION
1University of Melbourne Department of Surgery, Fitzroy, Australia.
2Department of Orthopaedic Surgery, St Vincent’s Hospital, Fitzroy, Australia.

Correspondence should be sent to: Jason Trieu, University of Melbourne Department of Surgery, Level 2, Clinical Sciences Building, 29 Regent Street, Fitzroy VIC 3065, Australia.
Email: trieu@student.unimelb.edu.au

REFERENCES
1. Cross M, Smith E, Hoy D, et al. The global burden of hip and knee osteoarthritis: estimates from the global burden of disease 2010 study. Ann Rheum Dis 2014;73:1323–1330.
2. Pabinger C, Lothaller H, Geissler A. Utilization rates of knee-arthroplasty in OECD countries. Osteoarthritis Cartilage 2015;23:1664–1673.
3. Palisi JA, Brehmer TS, Pellegrini VD, Drew JM, Sachs BL. The cost of joint replacement: comparing two approaches to evaluating costs of total hip and knee arthroplasty. J Bone Joint Surg Am 2018;100:326–333.
4. Healy WL, Della Valle CJ, Iorio R, et al. Complications of total knee arthroplasty: standardized list and definitions of the Knee Society. Clin Orthop Relat Res 2013;471:215–220.
5. Antonios JK, Korber S, Sivasundaram L, et al. Trends in computer navigation and robotic assistance for total knee arthroplasty in the United States: an analysis of patient and hospital factors. Arthroplast Today 2019;5:88–95.
6. Jones CW, Jerabek SA. Current role of computer navigation in total knee arthroplasty. J Arthroplasty 2018;33:1989–1993.
7. de Steiger RN, Liu YL, Graves SE. Computer navigation for total knee arthroplasty reduces revision rate for patients less than sixty-five years of age. J Bone Joint Surg Am 2015;97:635–642.
8. Dowsey MM, Smith AJ, Choong PF. Latent class growth analysis predicts long term pain and function trajectories in total knee arthroplasty: a study of 689 patients. Osteoarthritis Cartilage 2015;23:2141–2149.

ICMJE CONFLICT OF INTEREST STATEMENT
JT reports a scholarship from the University of Melbourne to support PhD candidature – not contingent on any specific piece of academic work.
MMD reports that this work was supported by a Centre for Research Excellence grant awarded by the NHMRC (APP1116325) to the author’s institution and that she is supported by a NHMRC Career Development Fellowship (APP1122526), all related to the submitted work; grants paid to her institution for unrelated research by the NHMRC, speaker honorarium from Pfizer, and investigator initiated study for Medacta International, Medibank and St. Vincent’s Health Australia, all unrelated to the submitted work.
PFC reports that this work was supported by a Centre for Research Excellence grant awarded by the NHMRC (APP1116325) to the author’s institution and that he is supported by a NHMRC Career Development Fellowship (APP1154203), all related to the submitted work; consultancy fees as member of Surgeon Advisory Board for Stryker, consultancy fees and royalties as a member of instrument design team for Johnson & Johnson, institutional support for RCT investigating relationship of prosthetic design and outcomes after total knee replacement from Medacta International, royalty fees as editor of edited text on orthopaedic surgery from Kluwer, and investigator initiated study for Medacta International, Medibank and St. Vincent’s Health Australia, all unrelated to the submitted work.

FUNDING STATEMENT
No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

OPEN ACCESS
© 2021 The author(s)
This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0) licence (https://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed.
9. Choong PF, Dowsey MM, Stoney JD. Does accurate anatomical alignment result in better function and quality of life? Comparing conventional and computer-assisted total knee arthroplasty. J Arthroplasty 2009;24:560–569.

10. Bravo Vergel Y, Sculpher M. Quality-adjusted life years. Pract Neurol 2008;8:175–182.

11. Ackerman I, Bohensky MA, Pratt C, Gorelik A, Liew D. Counting the cost: Part 1: Healthcare Costs, The current and future burden of arthritis. Melbourne EpiCentre, The University of Melbourne: Arthritis Australia, 2016.

12. Andrawis JP, Chenok KE, Bozic KJ. Health policy implications of outcomes measurement in orthopaedics. Clin Orthop Relat Res 2013, 471:3475–3481.

13. Amanatullah DF, McQuillan T, Kamal RN. Quality measures in total hip and knee arthroplasty. J Am Acad Orthop Surg 2019, 27:219–226.

14. Bilinski A, Neumann P, Cohen J, Thorat T, McDaniel K, Salomon JA. When cost-effective interventions are unaffordable: integrating cost-effectiveness and budget impact in priority setting for global health programs. PLoS Med 2014;11:e10002367-e.

15. Daigle ME, Weinstein AM, Katz JN, Losina E. The cost-effectiveness of total joint arthroplasty: a systematic review of published literature. Best Pract Res Clin Rheumatol 2012;26:649–658.

16. Boyle M, Suchman K, Vigdorchik J, Slover J, Bosco J. Technology-assisted hip and knee arthroplasties: an analysis of utilization trends. J Arthroplasty 2018;33:1019–1023.

17. Tricco AC, Lillie E, Zarin W, et al. PRISMA Extension for Scoping Reviews (PRISMA-ScR): checklist and explanation. Ann Intern Med 2018;169:467–473.

18. Center for the Evaluation of Value and Risk in Health, The Cost-Effectiveness Analysis Registry. Boston, Institute for Clinical Research and Health Policy Studies, Tufts Medical Center. www.cearegistry.org

19. Neumann PJ. Costing and perspective in published cost-effectiveness analysis. Med Care 2009;47:S28–S32.

20. Dong H, Buxton M. Early assessment of the likely cost-effectiveness of a new technology: a Markov model with probabilistic sensitivity analysis of computer-assisted total knee replacement. Int J Technol Assess Health Care 2006;22:191–202.

21. Novak EJ, Silverstein MD, Bozic KJ. The cost-effectiveness of computer-assisted navigation in total knee arthroplasty. J Bone Joint Surg Am 2007;89:2389–2397.

22. Slover JD, Tosteson ANA, Bozic KJ, Rubash HE, Malchau H. Impact of hospital volume on the economic value of computer navigation for total knee replacement. J Bone Joint Surg Am 2008;90:1492–1500.

23. Gothenes Ø, Slover J, Havelin I, Askildsen JE, Malchau H, Furnes O. An economic model to evaluate cost-effectiveness of computer assisted knee replacement surgery in Norway. BMC Musculoskelet Disord 2013;14:202.

24. Weinstein MC, Stason WB. Foundations of cost-effectiveness analysis for health and medical practices. N Engl J Med 1977;296:716–721.

25. Salati F, Carotti M, Giapetti A, Gasparini S, Grassi W. A comparison of utility measurement using EQ-5D and SF-6D preference-based generic instruments in patients with rheumatoid arthritis. Clin Exp Rheumatol 2011;29:660–671.

26. Cohen DJ, Reynolds MR. Interpreting the results of cost-effectiveness studies. J Am Coll Cardiol 2008;52:2119–2126.

27. Losina E, Walensky RP, Kessler CL, et al. Cost-effectiveness of total knee arthroplasty in the United States: patient risk and hospital volume. Arch Intern Med 2009;169:1111–1121.

28. Ferlet B, Feldman Z, Zhou J, Oei EH, Bierma-Zeinstra SMA, Mazumdar M. Impact of total knee replacement practice: cost effectiveness analysis of data from the Osteoarthritis Initiative. BMJ 2017;356:j3131.

29. Barbash GI, Gied SA. New technology and health care costs: the case of robot-assisted surgery. N Engl J Med 2010;363:701–704.

30. Bodenheimer T. High and rising health care costs. Part 2: technologic innovation. Ann Intern Med 2005;142:932–937.

31. Friedman RJ. Navigation in total knee arthroplasty: a procedure whose time has not come. Commentary on an article by Young-Hoo Kim, MD, et al. ‘The clinical outcome of computer-navigated compared with conventional knee arthroplasty in the same patients: a prospective, randomized, double-blind, long-term study’. J Bone Joint Surg Am 2017;99:E64.

32. Konopka JF, Lee YY, Su EP, McLawhorn AS. Quality-adjusted life years after hip and knee arthroplasty: health-related quality of life after 12,782 joint replacements. JBJS Open Access 2018;3:e0007.

33. Schilling C, Dowsey MM, Clarke PM, Choong PF. Using patient-reported outcomes for economic evaluation: getting the timing right. Value Health 2016;19:945–950.

34. Thiele K, Perka C, Matziolis G, Mayr HO, Sostheim M, Hube R. Current failure mechanisms after knee arthroplasty have changed: polyethylene wear is less common in revision surgery. J Bone Joint Surg Am 2015;97:715–720.

35. Katz JN, Barrett J, Mahomed NN, Baron JA, Wright RJ, Losina E. Association between hospital and surgeon procedure volume and the outcomes of total knee replacement. J Bone Joint Surg Am 2004;86:1909–1916.

36. Australian Orthopaedic Association. Hip, Knee & Shoulder Arthroplasty. Annual Report. 2018. Adelaide: Australian Orthopaedic Association

37. Berend ME, Ritter MA, Meding JB, et al. Tibial component failure mechanisms in total knee arthroplasty. Clin Orthop Relat Res 2004;428:26–34.

38. Reyes C, Leyland KM, Peat G, Cooper C, Arden NK, Prieto-Alhambra D. Association between overweight and obesity and risk of clinically diagnosed knee, hip, and hand osteoarthritis: a population-based cohort study. Arthritis Rheumatol 2016;68:1869–1875.

39. Petursson G, Fenstad AM, Gothenes Ø, et al. Computer-assisted compared with conventional total knee replacement: a multicenter parallel-group randomized controlled trial. J Bone Joint Surg Am 2018;100:1265–1274.