The Direct and Indirect Costs to Society of Treatment for End-Stage Knee Osteoarthritis

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Background: Although total knee arthroplasty for end-stage osteoarthritis is a cost-effective procedure, payers are focusing on its indications and cost because of its high and growing use. Improvements in pain and physical function from total knee arthroplasty could yield benefits in the form of increased work life and lower disability payments. The purpose of this study was to estimate the value of total knee arthroplasty from a societal perspective, including the costs and benefits to patients, employers, and payers.

Methods: A Markov model was used to estimate the value of total knee arthroplasty for patients with end-stage osteoarthritis of the knee by comparing direct and indirect costs between surgical and nonsurgical treatment scenarios. Direct costs included all medical costs for surgical and nonsurgical treatment of osteoarthritis of the knee. Indirect costs were related to lost wages due to an inability to work, lower earnings, or receipt of disability payments. Direct and indirect costs and quality-of-life measures were incorporated into the Markov model to estimate the impact of total knee arthroplasty on costs over patients' lifetimes and quality-adjusted life years. The assumptions used in the model were developed with use of claims and survey data as well as clinical expert opinion and the peer-reviewed literature.

Results: Compared with nonsurgical treatment, total knee arthroplasty increased lifetime direct costs by a mean of $20,635 (net present value in 2009 U.S. dollars). These costs were offset by societal savings of $39,565 from reduced indirect costs, resulting in a lifetime societal net benefit from total knee arthroplasty of $18,930 per patient. Eighty-five percent of these savings originated from increased employment and earnings, with the remaining 15% from fewer missed workdays and lower disability payments.

Conclusions: The estimated lifetime societal savings from the more than 600,000 total knee arthroplasties performed in the U.S. in 2009 were estimated to be approximately $12 billion. These societal savings primarily accrued to patients and employers. The study demonstrates the importance of a societal perspective when considering the costs and benefits of total knee arthroplasty and policies that will affect access to this procedure.

The past two decades have seen growth in the number of total knee arthroplasties performed in the U.S. A recent study shows that the number of primary total knee arthroplasties performed in fee-for-service Medicare beneficiaries increased 162% from 1991 to 2010[1]. In 2010, over 600,000 total knee arthroplasty procedures were performed across all age groups in the U.S.[1]. With an aging population, demand for total knee arthroplasty in the U.S. will continue to rise, with the total number of procedures expected to exceed three million by the year 2030[2].

The growing utilization of total knee arthroplasty is a reflection of several factors. The procedure is safe and effective, improving the quality of life for individuals with severe osteoarthritis of the knee[3,4]. The aging of the population and the increase in obesity contribute to a higher prevalence of osteoarthritis and a greater need for total knee arthroplasty, although these factors alone cannot account for the high growth in the procedure[5]. The most rapid increases in total knee arthroplasty in the U.S. are occurring in the working-age population; from 1997 to 2010, the percentage of all total knee arthroplasties that

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were performed in adults forty-five to sixty-four years of age increased substantially from 26% to 42%[6].

Studies have shown total knee arthroplasty to be a cost-effective procedure, with an incremental cost of $18,300 per quality-adjusted life year (QALY) for individuals in the Medicare program, including high-risk individuals[3]. Although a few studies have examined the economic burden of osteoarthritis, we are not aware of any studies that have examined the impact of total knee arthroplasty from a societal perspective[7-9]. Existing, but limited, literature supports a link between total knee arthroplasty for osteoarthritis and workforce participation, with the latter being a major component of societal costs[10-24]. However, this literature is based on small observational studies, and the strength of this link between total knee arthroplasty and work status is not well established[18]. We hypothesized that the economic effects of total knee arthroplasty may be substantial, particularly given the growth in knee replacement among individuals of working age and the trend among working adults to choose to delay retirement[25].

The purpose of this study was to estimate the value of total knee arthroplasty from a societal perspective by estimating its costs and benefits to patients, employers, payers, and government in the U.S. We used a Markov model framework with three primary components: (1) quality of life; (2) direct medical costs for the total knee arthroplasty, complications of surgery, and revision arthroplasty; and (3) indirect costs involving employment status, earnings, time missed from work (or absenteeism), and disability payments.

Materials and Methods

Modeling Approach

We developed a Markov cohort model for patients with end-stage osteoarthritis of the knee to assess the incremental costs and outcomes of total knee arthroplasty compared with nonsurgical treatment. This approach

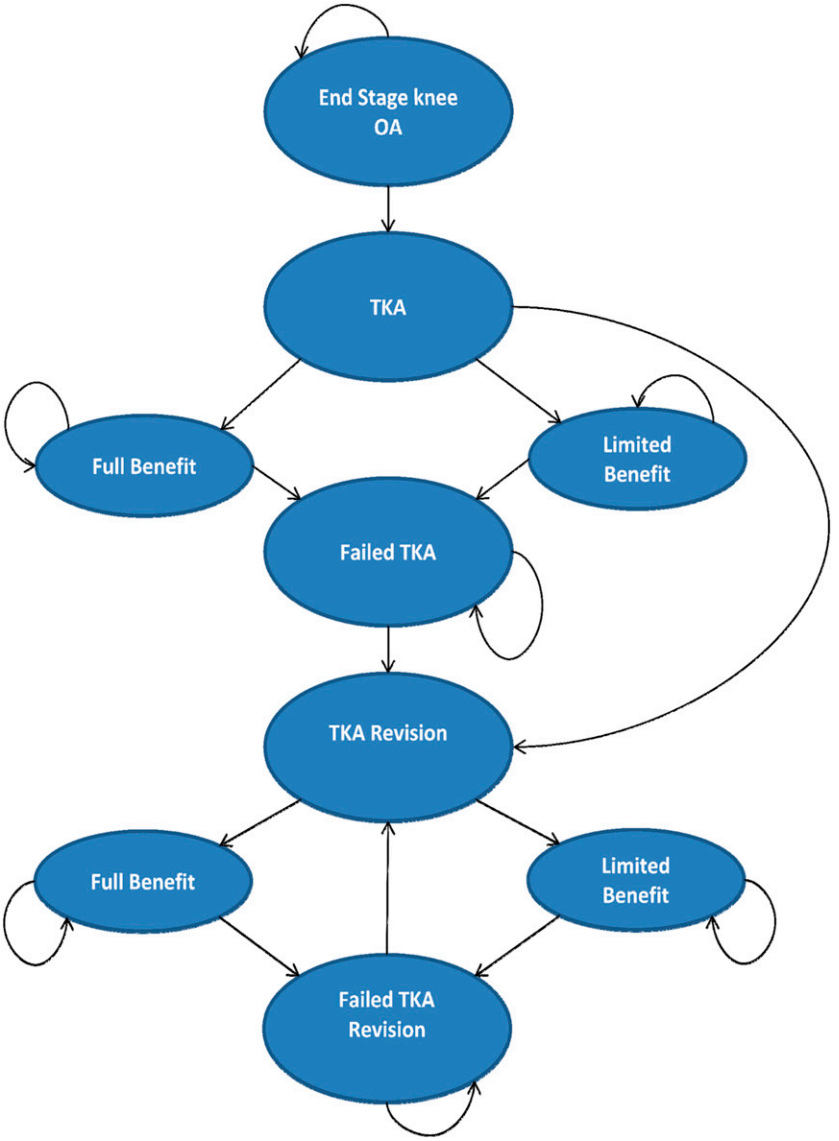

Fig. 1

Representation of the Markov model for end-stage knee osteoarthritis (OA). Death, an absorbing state, is not included in this representation. TKA = total knee arthroplasty.

TABLE I Utilities and Costs*

State	Utility	Direct Cost ($)
End-stage osteoarthritis of the knee	0.69†	5282†
Current primary TKA and rehabilitation	0.78†	24,247‡
Full benefit after primary or revision TKA	0.835†	4770†
Limited benefit after primary or revision TKA	0.76†	5282†
Current revision TKA and rehabilitation	0.781§	29,653‡
Failed primary TKA	0.5175†	7923†
Failed revision TKA	0.5175†	7923†
Death	0	0

*Estimates were adjusted to reflect different reimbursement rates across payers (e.g., private, Medicare, Medicaid). Estimates include costs from the index hospitalization to three months after discharge from the index hospitalization. All costs are expressed in 2009 dollars. TKA = total knee arthroplasty. †Assumption from Losina et al.[3] after converting from 2006 to 2009 dollars and adjusting for all-payer reimbursement levels. ‡Assumption derived from the authors' analysis of the Medicare 2009 5% Standard Analytic Inpatient file. §The utility value of 0.781 used for the primary and revision TKA health states was derived by averaging the utility before treatment and the weighted mean of the full and limited-benefit utilities after treatment.

considers the timing and probability of different patient outcomes. The Markov model calculates the present-day value of the expected (direct and indirect) costs and QALYs gained over the lifetime of a cohort of patients for each treatment strategy, with future costs and benefits discounted at a rate of 3% per year[26].

Model results were generated for the population forty years of age or older who received a total knee arthroplasty in the U.S. in 2009. This group accounted for 99% of all total knee arthroplasties performed in that year. For each age and treatment strategy, the direct cost, quality-of-life (termed utility), and disability payment components of the models were calculated until the age of ninety-nine years or mortality. Household income and missed workdays (accounting for age and sex-specific differences in income and workforce participation) were calculated until the age of seventy-five years, at which point workers were assumed to retire. An age-weighted mean of the model findings was obtained with use of the age distribution of patients undergoing total knee arthroplasty in 2009. The model operated on a one-year cycle.

The principal objective of the study was to determine the societal savings from total knee arthroplasty, measured as the difference between the total costs associated with surgical and nonsurgical treatment. Five outcomes were calculated in the model: (1) QALYs, which are the accumulation of years of life weighted by an indicator of quality ranging from 0 for death to 1 for a year in perfect health; (2) lifetime direct medical costs; (3) indirect cost components involving expected income (the product of income for a worker and the probability of working); (4) the value of missed days of work; and (5) expected disability payments (the product of mean disability payments and the probability of receiving Supplemental Security Income [SSI] because of a disability). These components were projected over the lifetime of individuals.

Markov Model

The structure of the Markov model and the assumed utilities (quality-of-life measures) and transition probabilities are derived from Losina et al.[3]. In accordance with that study, ten health states were included (Fig. 1). Two of these states are surgical (primary and revision total knee arthroplasty). An individual could not be in a particular surgery-related health state for more than one consecutive year at a time, whereas the remaining states were potentially chronic (e.g., a patient could stay in the full-benefit total knee arthroplasty state until death). After being in any state for one year, an individual was permitted to either transition to a chronic state or, if already in a chronic state, stay in his or her current state. Once in the primary or revision total knee arthroplasty surgical state, an individual was required to transition to the limited-benefit state, the full-benefit state, or an early failed total knee arthroplasty state after one year.

Transitions to either chronic state are dependent on WOMAC (Western Ontario and McMaster Universities Osteoarthritis Index) thresholds, normalized to a maximum possible score of 100 points, provided in Losina et al.[3]. Specifically, an individual with a postoperative WOMAC score of >60 points transitions to the full-benefit postoperative state, whereas an individual with a WOMAC score of ≤60 points transitions to the limited-benefit postoperative health state. Individual patients may stay in these health states for the remainder of their life or have a failure in the knee prosthesis and transition to the failed total knee arthroplasty health state. Once in the failed state, individuals may remain in that state or choose to undergo a revision total knee arthroplasty and transition to the revision total knee arthroplasty state. After this revision state, individuals will transition to either the post-revision full-benefit state or the post-revision limited-benefit state, where they may remain until they transition to either the failed revision total knee arthroplasty state or death.

Death is an absorbing state that could occur at any point, with a natural mortality probability based on sex and age data from U.S. Census Bureau life expectancy tables[27] (or with a combined natural mortality probability and surgical mortality probability if transitioning from a surgical state).

Direct Cost Estimates

The direct medical costs of surgical treatment were calculated with use of 2009 Medicare inpatient claims for a 5% sample of beneficiaries. The ICD-9 (International Classification of Diseases, Ninth Revision) diagnosis code "715.x6" was used to identify patients admitted to a hospital with a primary diagnosis of osteoarthritis of the knee. The ICD-9 procedure code "81.54" was used to identify treatment with total knee arthroplasty, and "81.55," "00.80," "00.81," "00.82," "00.83," and "00.84" were used to identify revision knee arthroplasty. The direct model costs included Medicare payments for inpatient care, physician services, and care provided in post-acute care facilities, such as skilled nursing facilities, hospice, home health care, inpatient rehabilitation facilities, and long-term care hospitals (Table I). These costs were tracked for three months after surgery, as our panel of clinical experts estimated that the expenses that accrued in this time period were most likely attributable to the

TABLE II Parameters for Each Health State*

Health State	Probability
Full benefit	0.88
Limited benefit	0.12
Failure within first year	0.0105
Failure within first year and undergoing revision	1.0
Surgical mortality	0.0063 × natural mortality
Failure after first year	0.0134
Failure after first year and undergoing revision	0.5

*Source: Losina et al.[3]. Natural mortality was obtained from U.S. Census data.

TABLE III Summary of Benefits from Surgical Treatment According to Age*

Age Group *(yr)*	Direct Cost Offsets *($)*	Total Societal Savings *($)*	Net Societal Savings *($)*	QALY Difference
40-44	19,232	177,342	158,110	3.4
45-49	19,428	149,930	130,503	3.2
50-54	19,637	119,521	99,884	3.1
55-59	19,871	85,263	65,391	2.9
60-64	20,167	50,531	30,364	2.6
65-69	20,523	22,398	1875	2.4
70-79	21,193	6520	−14,672	2.1
≥80	22,339	2978	−19,362	1.8
All†	20,635	39,565	18,930	2.4

*Source: authors' calculations. †Age-weighted mean based on the distribution of total knee arthroplasties performed in the U.S. in 2009.

arthroplasty surgery. Additionally, we estimated the mean cost of physical therapy visits over this time period to be $2016 (net present value in 2009 U.S. dollars) and included it as part of the rehabilitation costs associated with primary or revision total knee arthroplasty. Because payer and patient costs were derived with use of Medicare payments, we applied an adjustment to the direct costs estimated under Medicare to account for non-Medicare payments for persons younger than sixty-five years (see Appendix).

The costs of perioperative complications ($17,514 per year) and end-stage osteoarthritis ($5282 per year) for the Medicare population were obtained from Losina et al.[3], adjusted for an all-payer population, and converted to 2009 dollars. Costs accrued within one year of primary and revision total knee arthroplasty were calculated as the cost of the relevant procedure plus the equally weighted expected cost of experiencing the limited-benefit or full-benefit state.

Indirect Cost Estimates

The effects of knee osteoarthritis on indirect costs were estimated with use of methods and data from the National Health Interview Survey (NHIS) reported by Dall et al. regarding functional limitations, employment, missed workdays, income, and disability payments[28]. These findings allowed us to predict an individual's probability of being employed, number of missed workdays (if working), household earnings (if working), and probability of receiving SSI disability payments conditional on his or her level of functional ability in a given year (see Appendix).

Predicted values for indirect cost components were obtained by utilizing patient-reported data on pre-surgery and post-surgery functional status collected by a large orthopaedic group practice. Electronic questionnaires were sent to 310 patients who received a total knee arthroplasty from September 2010 to April 2011. A total of seventy-three responses were received and used in the analyses. The survey contained questions regarding an individual's socioeconomic status and functional ability (using the questions on functional status from the NHIS) prior to obtaining surgery and after receiving surgery. Functional questions included the following possible answers: "no difficulty," "only a little difficult," "somewhat difficult," "very difficult," and "cannot do." Numerical values of 1 through 5 were assigned to the responses, with "no difficulty" assigned a value of 1 and "cannot do" assigned a value of 5. Patients were categorized as receiving full benefit from the total knee arthroplasty if their mean post-surgery response averaged over all functional questions was ≤3 (somewhat difficult) and as receiving limited benefit otherwise. Assuming this response categorization allowed us to match the distribution of patients experiencing full benefit from total knee arthroplasty (88%) in the study by Losina et al.[3] (Table II).

TABLE IV Direct Medical Costs and QALYs According to Age and Treatment*

	Total Direct Costs *($)*			QALYs		
Age Group *(yr)*	Surgery	No Surgery	Difference	Surgery	No Surgery	Difference
40-44	142,437	123,205	19,232	18.8	15.4	3.4
45-49	134,684	115,256	19,428	17.6	14.4	3.2
50-54	126,346	106,710	19,637	16.3	13.2	3.1
55-59	117,032	97,161	19,871	14.9	12.0	2.9
60-64	107,069	86,902	20,167	13.3	10.7	2.6
65-69	96,232	75,709	20,523	11.6	9.2	2.4
70-79	80,071	58,878	21,193	9.1	7.0	2.1
≥80	60,866	38,527	22,339	6.1	4.3	1.8

*Source: authors' calculations.

TABLE V Sensitivity Analysis of Selected Model Parameters*

Parameter	Base Model Value	Value Range	Range of Net Societal Savings† ($)	Range of QALY Difference†
Utility in limited-benefit state	0.76	0.57-0.95	NA	2.30-2.52
Utility in full-benefit state	0.835	0.626-0.1	NA	1.50-3.21
Rate of transition to limited-benefit state	0.12	0.09-0.20	21,015-13,371	2.43-2.33
Rate of medical complications	0.028	0.003-0.052	19,405-18,455	NA
Rate of death from surgery	0.0063 × natural mortality	0.0047-0.0079	18,886-18,960	2.42-2.38
Cost of end-stage osteoarthritis	$5282	$3962-$6603	8935-28,899	NA
Cost of primary total knee arthroplasty	$24,247	$18,185-$30,309	13,064-24,796	NA
Cost of revision total knee arthroplasty	$29,653	$22,240-$37,066	19,955-17,905	NA
Cost of perioperative complications	$17,514	$13,135-$21,893	19,081-18,779	NA
SSI payments for full-benefit state	Varies by age	25% intervals (50% decrease)	17,109-20,751 (15,288)	NA
Income for full-benefit state	Varies by age	25% intervals (50% decrease)	9762-28,098 (594)	NA
Missed workdays for full-benefit state	Varies by age	25% intervals (50% decrease)	18,883-18,997 (18,836)	NA
SSI payments for limited-benefit state	Varies by age	25% intervals (50% decrease)	18,840-19,020 (19,110)	NA
Income for limited-benefit state	Varies by age	25% intervals (50% decrease)	19,734-18,126 (20,539)	NA
Missed workdays for limited-benefit state	Varies by age	25% intervals (50% decrease)	18,937-18,923 (18,945)	NA

*Source: authors' calculation. NA = not applicable. †Age-weighted mean based on the distribution of total knee arthroplasties performed in the U.S. in 2009.

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This study was funded by the American Academy of Orthopaedic Surgeons (AAOS).

Results

Relative to nonsurgical treatment, the mean lifetime net societal savings per patient resulting from total knee arthroplasty was $18,930 (Table III). Each knee arthroplasty increased lifetime direct costs by a mean of $20,635, while the societal savings in lower indirect costs from improved functional status averaged $39,565. Eighty-five percent of these savings originated from increased income, through a combination of increased probability of working and higher earnings. The remaining 15% of societal savings resulted from fewer missed workdays and lower disability payments. Although our results showed net societal savings from total knee arthroplasty in the full cohort of patients, direct medical costs from total knee arthroplasty began to exceed societal savings at a patient age of seventy years at the time of the index procedure, indicating a crossover from positive net societal savings from total knee arthroplasty procedures to negative net societal savings.

The youngest patients receiving a total knee arthroplasty predictably accrued substantially higher lifetime savings associated with surgery because they accrued benefits over more years than elderly patients. The difference in societal savings between the oldest age group (≥80 years) and youngest group (forty to forty-four years) was $174,364 over a lifetime (Table III). The only savings accrued for retired patients involved lower disability benefits, which were relatively small compared with earnings. For patients younger than sixty years, the net increase in societal savings resulting from surgery ranged from $85,263 (fifty-five to fifty-nine years old) to $177,342 (forty to forty-four years old).

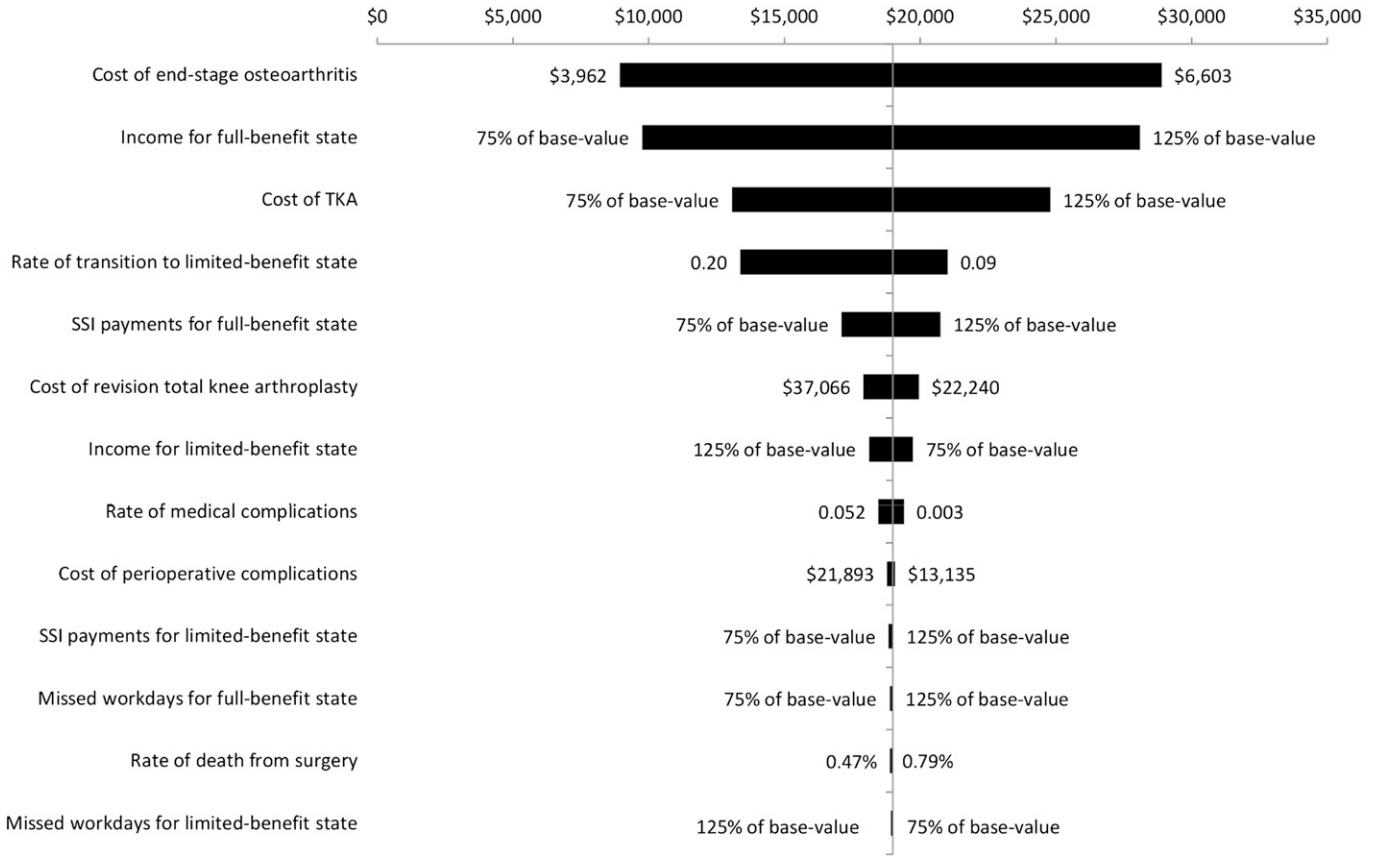

Fig. 2

Sensitivity analysis of total societal savings (net savings in direct and indirect costs) from total knee arthroplasty. The base value of societal savings was $18,930. OA = osteoarthritis, and TKA = total knee arthroplasty.

The difference in total direct medical costs between surgical and nonsurgical treatment increased with age. For patients in the forty to forty-four-year age group, the lifetime direct medical costs of surgery were $19,232 greater than the direct medical costs of nonsurgical treatment (Table IV). For patients eighty years of age or older, the difference in lifetime direct medical costs was $22,339. The higher incremental cost of surgery compared with nonsurgical treatment for older patients is driven by the assumption that post-surgery medical spending for patients who undergo total knee arthroplasty is less than that for patients treated nonoperatively. Younger patients are able to accrue savings from lower medical spending after total knee arthroplasty over a longer time period compared with older patients. Although the savings from lower medical costs after total knee arthroplasty do not fully offset the cost of the procedure, they reduce the difference in direct medical costs between the surgical and nonsurgical treatment options.

Our model demonstrated large QALY increases from total knee arthroplasty as a result of higher quality of life for patients treated surgically compared with nonsurgically. For patients from forty to forty-four years of age, surgery resulted in an increase of 3.4 QALYs. The principal outcome calculated was the incremental cost effectiveness ratio (ICER), which is the ratio of the cost difference between the treatment options and the corresponding QALY difference. Considering only direct costs, this implies an ICER of $5656 for total knee arthroplasty in the entire cohort. In comparison, the improvement for those eighty years old or older was 1.8 QALYs, with an ICER of $12,410. Thus, our model demonstrates that total knee arthroplasty was cost-effective across all age groups, assuming a willingness-to-pay threshold of $50,000 per QALY gained.

We performed a one-way sensitivity analysis on our assumptions regarding direct costs, utility measures, and relevant transition probabilities (Fig. 2). In this analysis, the cost effectiveness in cohorts ranging from forty to ninety-nine years of age was recalculated as the assumed value of each single parameter was varied. The net societal savings reported in Table V are mean (age-weighted) values across all age groups. The sensitivity analysis indicated that the QALY changes resulting from surgery were robust to the investigated level of variation in the utility for the full-benefit state. Net societal savings remained positive with variations in the transition probabilities and the costs associated with end-stage osteoarthritis of the knee, primary and revision total knee arthroplasty, and perioperative complications.

We found little variation in net societal savings from variations in disability payments and in expected missed workdays. The results were more sensitive to changes in

expected income increases from the full-benefit state. When the simulated expected income was decreased by 25%, the positive net savings dropped from $18,930 to $9762.

Discussion

Primary and revision total knee arthroplasty involving a wide array of methods and prostheses are cost-effective[29-33]. However, to our knowledge the present study is the first to focus on the societal value of total knee arthroplasty, taking into account a broad array of economic outcomes, for the full cohort of patients receiving this procedure. We confirmed that total knee arthroplasty is a cost-effective intervention for individuals with end-stage osteoarthritis of the knee. Furthermore, we demonstrated positive net societal savings for patients younger than seventy years of age at the time of surgery, and we demonstrated an age-weighted positive net benefit of $18,930 over all ages.

Our analysis expands on the analysis of Losina et al.[3] in four important ways. First, we updated and expanded the direct medical costs associated with total knee arthroplasty by conducting an analysis of 2009 Medicare claims. Second, we estimated the cost-effectiveness of total knee arthroplasty for the full cohort of patients receiving the procedure in 2009, including the growing segment of working-age individuals receiving knee replacement surgery. Third, we adjusted reimbursement levels for an all-payer population. Fourth, we incorporated indirect costs related to employment, earnings, and disability payments into the model to generate findings from a societal perspective.

The calculated ICER for individuals sixty-five years of age or older differs from the $18,300 reported previously by Losina et al.[3]. The difference in direct medical costs for total knee arthroplasty between our study (ranging from $20,523 for the sixty-five to sixty-nine-year age cohort to $22,339 for the eighty-year-and-older cohort) and that of Losina et al.[3] ($20,800) was small. The key factor leading to our lower (better) calculated ICER is the greater estimated QALY increase from surgery in the present study (ranging from 2.4 additional QALYs for the sixty-five to sixty-nine-year age cohort to 1.8 additional QALYs for the eighty-year-and-older cohort) compared with the study by Losina et al.[3] (1.4 additional QALYs for the Medicare population). The QALY difference may be due to our assignment of higher utility values in the primary and revision total knee arthroplasty health states. Specifically, we assigned a mean utility value based on pre-surgery and post-surgery utility values.

This study has several limitations that are worth noting and represent areas for future research. First, we applied the same utility assumptions for all patients reaching the full-benefit health state as well as for all patients reaching the limited-benefit health state. These utility levels were obtained from the study by Losina et al.[3], which is based on Medicare-age patients receiving total knee arthroplasty and may therefore understate the initial benefits received by a younger population that experiences better recuperation. Second, patient outcome data were obtained retrospectively from patients up to two years following total knee arthroplasty, introducing the possibility of recall bias regarding functional limitations prior to surgery. However, the functional scores reported in our survey are comparable with those in the existing literature (see Appendix)[4,12,34]. Third, we inferred the effects of total knee arthroplasty on indirect costs by linking osteoarthritis of the knee, functional limitations, and economic outcomes (e.g., employment). This was done because of the lack of published evidence. Fourth, our estimates of net societal savings from knee replacement are based on mean indirect cost reductions for individuals who undergo the procedure. However, not all of these individuals will have had equal osteoarthritis severity, as suggested by large geographic variations in the total knee arthroplasty rate[35,36]. Thus, careful consideration of individual patient needs and alternatives to total knee arthroplasty may further increase the estimated value of the procedure.

Finally, the societal savings calculated in the present study may be conservative because we did not account for workplace productivity, depression-related symptoms, cardiovascular health, home modification costs, and nursing home costs. Workers having advanced pain due to osteoarthritis report lower productivity at work compared with those with more limited symptoms[7,8]. A study of Medicare data documented reduced mortality and fewer cardiovascular events for patients with end-stage osteoarthritis of the knee who undergo total knee arthroplasty compared with those who do not[37].

We estimated total lifetime societal savings of approximately $12 billion (net present value in 2009 dollars) from the more than 600,000 total knee arthroplasties performed in the U.S. in 2009. These benefits will accrue primarily to the patients in the form of additional working years and increased income while in the workforce. These findings demonstrate the importance of using a societal perspective for evaluating the costs and benefits of knee replacement surgery. With the expected continued growth of total knee arthroplasty, there will be increased pressure on payers to reduce the use of this procedure by imposing coverage restrictions or higher copayments. Our study demonstrates the potential for substantial negative societal effects if payers and policy makers unduly restrict access to appropriate total knee arthroplasty.

Appendix

eA An appendix and tables showing our methodology for estimating indirect costs and other model components are available with the online version of this article as a data supplement at jbjs.org. ■

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References

1. Cram P, Lu X, Kates SL, Singh JA, Li Y, Wolf BR. Total knee arthroplasty volume, utilization, and outcomes among Medicare beneficiaries, 1991-2010. JAMA. 2012 Sep 26;308(12):1227-36.

2. Kurtz SM, Lau E, Ong K, Zhao K, Kelly M, Bozic KJ. Future young patient demand for primary and revision joint replacement: national projections from 2010 to 2030. Clin Orthop Relat Res. 2009 Oct;467(10):2606-12. Epub 2009 Apr 10.

3. Losina E, Walensky RP, Kessler CL, Emrani PS, Reichmann WM, Wright EA, Holt HL, Solomon DH, Yelin E, Paltiel AD, Katz JN. Cost-effectiveness of total knee arthroplasty in the United States: patient risk and hospital volume. Arch Intern Med. 2009 Jun 22;169(12):1113-21; discussion 1121–2.

4. Hawker GA, Badley EM, Croxford R, Coyte PC, Glazier RH, Guan J, Harvey BJ, Williams JI, Wright JG. A population-based nested case-control study of the costs of hip and knee replacement surgery. Med Care. 2009 Jul;47(7):732-41.

5. Losina E, Thornhill TS, Rome BN, Wright J, Katz JN. The dramatic increase in total knee replacement utilization rates in the United States cannot be fully explained by growth in population size and the obesity epidemic. J Bone Joint Surg Am. 2012 Feb 1;94(3):201-7.

6. Agency for Healthcare Research and Quality. HCUP Nationwide Inpatient Sample. http://www.hcup-us.ahrq.gov/nisoverview.jsp. Accessed 11 Oct 2012.

7. Dibonaventura MD, Gupta S, McDonald M, Sadosky A, Pettitt D, Silverman S. Impact of self-rated osteoarthritis severity in an employed population: cross-sectional analysis of data from the national health and wellness survey. Health Qual Life Outcomes. 2012;10(30):30. Epub 2012 Mar 15.

8. Md Dibonaventura, Gupta S, McDonald M, Sadosky A. Evaluating the health and economic impact of osteoarthritis pain in the workforce: results from the National Health and Wellness Survey. BMC Musculoskelet Disord. 2011;12(83):83. Epub 2011 Apr 28.

9. Yelin E, Cisternas MG, Pasta DJ, Trupin L, Murphy L, Helmick CG. Medical care expenditures and earnings losses of persons with arthritis and other rheumatic conditions in the United States in 1997: total and incremental estimates. Arthritis Rheum. 2004 Jul;50(7):2317-26.

10. Sayre EC, Li LC, Kopec JA, Esdaile JM, Bar S, Cibere J. The effect of disease site (knee, hip, hand, foot, lower back or neck) on employment reduction due to osteoarthritis. PLoS One. 2010;5(5):e10470. Epub 2010 May 03.

11. Jones CA, Voaklander DC, Suarez-Alma ME. Determinants of function after total knee arthroplasty. Phys Ther. 2003 Aug;83(8):696-706.

12. Jones CA, Voaklander DC, Johnston DW, Suarez-Almazor ME. The effect of age on pain, function, and quality of life after total hip and knee arthroplasty. Arch Intern Med. 2001 Feb 12;161(3):454-60.

13. Hootman JM, Helmick CG. Projections of US prevalence of arthritis and associated activity limitations. Arthritis Rheum. 2006 Jan;54(1):226-9, doi:10.1002/art.21562.

14. Dionne CE, Von Korff M, Koepsell TD, Deyo RA, Barlow WE, Checkoway H. A comparison of pain, functional limitations, and work status indices as outcome measures in back pain research. Spine (Phila Pa 1976). 1999 Nov 15;24(22):2339-45.

15. Fautrel B, Hilliquin P, Rozenberg S, Allaert FA, Coste P, Leclerc A, Rossignol M. Impact of osteoarthritis: results of a nationwide survey of 10,000 patients consulting for OA. Joint Bone Spine. 2005 May;72(3):235-40.

16. Gupta S, Hawker GA, Laporte A, Croxford R, Coyte PC. The economic burden of disabling hip and knee osteoarthritis (OA) from the perspective of individuals living with this condition. Rheumatology (Oxford). 2005 Dec;44(12):1531-7. Epub 2005 Aug 09.

17. Bieleman HJ, Bierma-Zeinstra SMA, Oosterveld FGJ, Reneman MF, Verhagen AP, Groothoff JW. The effect of osteoarthritis of the hip or knee on work participation. J Rheumatol. 2011 Sep;38(9):1835-43. Epub 2011 Jun 15.

18. Lyall H, Ireland J, El-Zebdeh MY. The effect of total knee replacement on employment in patients under 60 years of age. Ann R Coll Surg Engl. 2009 Jul;91(5):410-3. Epub 2009 Apr 02.

19. Norman-Taylor FH, Palmer CR, Villar RN. Quality-of-life improvement compared after hip and knee replacement. J Bone Joint Surg Br. 1996 Jan;78(1):74-7.

20. Desmeules F, Dionne CE, Belzile E, Bourbonnais R, Frémont P. The burden of wait for knee replacement surgery: effects on pain, function and health-related quality of life at the time of surgery. Rheumatology (Oxford). 2010 May;49(5):945-54. Epub 2010 Feb 08.

21. Jorn LP, Johnsson R, Toksvig-Larsen S. Patient satisfaction, function and return to work after knee arthroplasty. Acta Orthop Scand. 1999 Aug;70(4):343-7.

22. Lerner D, Reed JI, Massarotti E, Wester LM, Burke TA. The Work Limitations Questionnaire's validity and reliability among patients with osteoarthritis. J Clin Epidemiol. 2002 Feb;55(2):197-208.

23. Palmer KT. The older worker with osteoarthritis of the knee. Br Med Bull. 2012 Jun;102:79-88. Epub 2012 Apr 26.

24. Palmer KT, Milne P, Poole J, Cooper C, Coggon D. Employment characteristics and job loss in patients awaiting surgery on the hip or knee. Occup Environ Med. 2005 Jan;62(1):54-7.

25. Toossi M. Labor force projections to 2020: a more slowly growing workforce. Mon Labor Rev. 2012 Jan:43-64. http://www.bls.gov/opub/mlr/2012/01/art3full.pdf.

26. West RR, McNabb R, Thompson AG, Sheldon TA, Grimley Evans J. Estimating implied rates of discount in healthcare decision-making. Health Technol Assess. 2003;7(38):1-60.

27. United States Census Bureau. The 2012 statistical abstract. births, deaths, marriages, & divorces. 2012 Jun. http://www.census.gov/compendia/statab/cats/births_deaths_marriages_divorces.html. Accessed

28. Dall TM, Gallo P, Koenig L, Gu Q, Ruiz D. Modeling the indirect economic implications of musculoskeletal disorders and treatment. Cost Eff Resour Alloc. 2013;11(1):5. Epub 2013 Mar 15.

29. Burns AWR, Bourne RB, Chesworth BM, MacDonald SJ, Rorabeck CH. Cost effectiveness of revision total knee arthroplasty. Clin Orthop Relat Res. 2006 May;446:29-33.

30. Novak EJ, Silverstein MD, Bozic KJ. The cost-effectiveness of computer-assisted navigation in total knee arthroplasty. J Bone Joint Surg Am. 2007 Nov;89(11):2389-97.

31. Rissanen P, Aro S, Sintonen H, Asikainen K, Slätis P, Paavolainen P. Costs and cost-effectiveness in hip and knee replacements. A prospective study. Int J Technol Assess Health Care. 1997 Fall;13(4):575-88.

32. Lavernia CJ, Guzman JF, Gachupin-Garcia A. Cost effectiveness and quality of life in knee arthroplasty. Clin Orthop Relat Res. 1997 Dec;345:134-9.

33. 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 Sep;86(9):1909-16.

34. Lingard EA, Katz JN, Wright RJ, Wright EA, Sledge CB; Kinemax Outcomes Group. Validity and responsiveness of the Knee Society Clinical Rating System in comparison with the SF-36 and WOMAC. J Bone Joint Surg Am. 2001 Dec;83(12):1856-64.

35. Fisher ES, Bell J-E, Tomek IM, Esty A, Goodman DC. Trends and regional variation in hip, knee, and shoulder replacement. A Dartmouth Atlas surgery report. 6 Apr 2010. http://www.dartmouthatlas.org/downloads/reports/Joint_Replacement_0410.pdf.

36. Center for the Evaluative Clinical Sciences. Preference-sensitive care. A Dartmouth Atlas project topic brief. 15 Jan 2007. http://www.dartmouthatlas.org/downloads/reports/preference_sensitive.pdf

37. Lovald ST, Ong KL, Lau EC, Schmier JK, Bozic KJ, Kurtz SM. Mortality, cost, and health outcomes of total knee arthroplasty in Medicare patients. J Arthroplasty. 2013 Mar;28(3):449-54. Epub 2012 Nov 08.

38. Centers for Disease Control and Prevention. National Health Interview Survey 2010. http://www.cdc.gov/nchs/nhis/quest_data_related_1997_forward.htm#2010_NHIS.

39. Ginsburg PB. Wide variation in hospital and physician payment rates evidence of provider market power. Res Brief. 2010 Nov; (16):1-11.

40. Medicare Payment Advisory Commission. Report to the Congress: Medicare payment policy. 2005 Mar. http://www.medpac.gov/publications/congressional_reports/Mar05_EntireReport.pdf.

41. Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. J Rheumatol. 1988 Dec;15(12):1833-40.