Estimating the Societal Benefits of THA After Accounting for Work Status and Productivity: A Markov Model Approach

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Abstract

Background Demand for total hip arthroplasty (THA) is high and expected to continue to grow during the next decade. Although much of this growth includes working-aged patients, cost-effectiveness studies on THA have not fully incorporated the productivity effects from surgery.

Questions/Purposes We asked: (1) What is the expected effect of THA on patients’ employment and earnings? (2) How does accounting for these effects influence the cost-effectiveness of THA relative to nonsurgical treatment?

Methods Taking a societal perspective, we used a Markov model to assess the overall cost-effectiveness of THA compared with nonsurgical treatment. We estimated direct medical costs using Medicare claims data and indirect costs (employment status and worker earnings) using regression

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models and nonparametric simulations. For direct costs, we estimated average spending 1 year before and after surgery. Spending estimates included physician and related services, hospital inpatient and outpatient care, and postacute care. For indirect costs, we estimated the relationship between functional status and productivity, using data from the National Health Interview Survey and regression analysis. Using regression coefficients and patient survey data, we ran a nonparametric simulation to estimate productivity (probability of working multiplied by earnings if working minus the value of missed work days) before and after THA. We used the Australian Orthopaedic Association National Joint Replacement Registry to obtain revision rates because it contained osteoarthritis-specific THA revision rates by age and gender, which were unavailable in other registry reports. Other model assumptions were extracted from a previously published cost-effectiveness analysis that included a comprehensive literature review. We incorporated all parameter estimates into Markov models to assess THA effects on quality-adjusted life years and lifetime costs. We conducted threshold and sensitivity analyses on direct costs, indirect costs, and revision rates to assess the robustness of our Markov model results.

**Results** Compared with nonsurgical treatments, THA increased average annual productivity of patients by USD 9503 (95% CI, USD 1446–USD 17,812). We found that THA increases average lifetime direct costs by USD 30,365, which were offset by USD 63,314 in lifetime savings from increased productivity. With net societal savings of USD 32,948 per patient, total lifetime societal savings were estimated at almost USD 10 billion from more than 300,000 THAs performed in the United States each year.

**Conclusions** Using a Markov model approach, we show that THA produces societal benefits that can offset the costs of THA. When comparing THA with other nonsurgical treatments, policymakers should consider the long-term benefits associated with increased productivity from surgery.

**Level of Evidence** Level III, economic and decision analysis.

## Introduction

Total hip arthroplasty (THA) is a highly successful medical intervention, having favorable long-term outcomes in terms of improvement of physical functioning, survivorship, and self-reported quality of life [2, 6, 24]. The increased medical costs from surgery per quality-adjusted life year (QALY) gained compares favorably with those of other surgical procedures, such as lumbar discectomy, rotator cuff repair, and ACL repair [18, 21, 22, 25, 26, 34]. Chang et al. [9] showed that THA could be cost saving for some patients compared with nonoperative treatment for end-stage osteoarthritis (OA) after accounting for avoided costs for nursing homes and other long-term care.

Owing in part to the aging population and expanded indications, the number of THAs in the United States is expected to increase substantially. Across all patients, primary THA is projected to grow by 75% from 293,094 to 511,837 between 2010 and 2020 [20]. People younger than 65 years represent the fastest growing segment of patients having THAs, accounting for 47% of all THAs performed in 2012 compared with 34% in 1997 [15, 16]. One study projected that more than 50% of THAs will be performed in patients younger than 65 years by 2030 [19].

The current emphasis on reducing healthcare expenditures may cause payers to limit utilization of THA by implementing restrictive coverage or reimbursement policies. For example, in Oregon, a health plan for state workers has placed enhanced cost-sharing requirements on joint replacement, to reduce spending on the procedure. The consequences of such policies will depend on the societal benefits derived from THA. Because working-age patients represent a large number of all patients having THAs, potentially important indirect benefits from THA relate to work status, such as maintaining employment, reducing missed work days, and increasing workplace productivity [28]. However, we are unaware of any studies that account for work-related (indirect cost) benefits of surgery.

The goal of our study was to determine the net societal value of THA in the United States by estimating societal costs and benefits. We build on the approach used by Dall et al. [11] and Ruiz et al. [35], which links functional status and economic outcomes to changes in patient outcomes from surgery. The research addresses two questions: the effects of surgery on employment and earnings and how the inclusion of these factors influenced the measured cost-effectiveness of THA relative to nonsurgical treatment.

## Materials and Methods

We investigated the cost-effectiveness of THA compared with nonoperative treatment for patients with OA of the hip using a state-transition Markov decision model (Fig. 1). Benefits were estimated from the societal perspective for a patient cohort that had THAs. The cycle length was one year and the model cycled until patient death. The primary effectiveness outcome was expressed in QALYs. We used Medicare payments adjusted to an all-payer population to account for higher payment rates from private payers relative to Medicare. Costs and utilities were discounted at 3% per year. The model and analyses were performed using a decision analysis software package (TreeAge Pro;
Our decision tree consisted of two primary treatment arms: THA and nonoperative treatment. There were eight health states associated with the two treatment arms, including six Markov health states (Fig. 1), one transitional health state, and one absorbing state. In the Markov process for THA (Fig. 1B), post-first revision THA represents failure of the primary THA. The model differentiates between early and late failure of surgery and revisions attributable to infection and asepsis. Post-second THA revision is a transitional health state. A patient may transition to a second THA revision after entering the post-first THA revision state or stay in the post-first THA revision state. Death was an absorbing state that could occur at any point in the model based on the natural mortality rates from the US Census Bureau’s life expectancy tables [39]. If a patient transitions from a surgical state, the probability of death is a combination of the probability of natural mortality and surgical mortality, which varied by age and gender. Patients who enter the nonoperative treatment arm cannot cross over to the surgical arm. While this assumption might not reflect clinical reality, we imposed this requirement because we were interested in the value of access to THA.

### Model Assumptions

**Indirect Costs**

Our approach for estimating indirect costs was based on the methods used by Dall et al. [11]. We used National Health Interview Survey (NHIS) [7] data to generate regression coefficients that described the statistical relationship between physical functioning and economic outcomes. We then applied regression coefficients to patient-reported outcomes data to estimate the effects of surgery on the likelihood of employment, earnings, and missed work days. The relationship between earnings and functional status was estimated using a two-stage Heckman selection model to correct for potential bias created because earnings are not observed for nonemployed individuals. We used a probit model to predict employment and a linear regression equation to predict earnings. The explanatory variables in both models included age, race, marital status, family size, education, and functional status indicators. Other sources of income and the presence of other working household members were included in the employment model. We used multiple imputation techniques to correct for the deflated standard errors that resulted from imputing personal income data in the NHIS [37].

Retrospective patient-reported outcomes data were obtained at two large physician group practices. Patients were asked to report on functional limitations using questions from the NHIS, which relate to ability to walk a quarter mile, climb 10 steps, sit for 2 hours, stand for 2
hours, stoop, carry a 10-pound bag, and push a large object. Respondents were asked to report functional ability at the time of the survey (followup) and to recall their function just before THA (baseline). We obtained 77 usable responses from patients (average age, 60 years; SD, 10.94 years) who generally received the survey 12 to 24 months after THA (Appendix 1. Supplemental material is available with the online version of CORR®).

We used a simulation-based approach to estimate the change in productivity between baseline and followup. For each iteration, we sampled 77 patients (with replacements) from the patient-reported outcomes dataset. We then applied patient responses to the functional assessment questions to the Heckman model parameter estimates to calculate the probability of employment and earnings conditional on employment at baseline and followup for each individual in the sample. We ran 1000 iterations of the simulation. For each sample, we calculated the change in mean productivity (equal to expected earnings) between baseline and followup. We then calculated a mean change in productivity across all 1000 samples and the 95% CI using the distribution of mean change in productivity.

To generate results by age group and gender, we used the functional status of the original sample of 77 responses and predicted the probability of employment and earnings by altering respondents’ age and gender. We used this approach because employment and earnings are likely to vary substantially by age and gender, and we did not have enough observations to run the simulation by age-gender subgroups. The findings on estimated changes in productivity by age and gender were incorporated in the Markov decision model. Additional assumptions included: workers missed an average of 40 work days to recover from THA [12]; initial postsurgery year total costs were a combination of medical costs and 50% of societal savings; and all patients retired by the age of 75 years (ie, no indirect cost benefits accrue after 74 years).

The study was approved by the institutional review board in both practices. Detailed descriptions of patient-reported outcome data, the estimated relationship between functional limitations and indirect costs, and the indirect cost assumptions are provided (Appendix 1. Supplemental material is available with the online version of CORR®).

**Direct Costs**

We used the Medicare Carrier, Home Health Agency, Inpatient, Outpatient, and Skilled Nursing Facility 5% sample Limited Data Sets [8] from 2009 to 2011 to estimate direct costs for THAs and revision THAs. Patients who received THA were identified using ICD-9 procedure code 81.51 with a principal diagnosis of hip osteoarthritis (ICD-9 diagnosis code 715.x5). We identified instances of revision hip replacement using ICD-9 procedure code 81.53. The sample was limited to patients with Medicare Part A and Part B coverage. We excluded patients who died during the episode period or who had multiple primary hip replacements.

Our direct cost estimate for surgical patients was computed by averaging total payments 1 year after surgery. We assumed that, if these patients had not received surgery, their healthcare utilization in the subsequent year would equal prior-year utilization. For revision, we computed direct costs for 3 months following revision, and assumed that direct costs for the remainder of the year resembled those of patients who had primary hip replacement. Direct costs include spending for services provided in hospitals (inpatient and outpatient), home, physician offices, and postacute care settings. Payments were inflated to 2011 US dollars using the Medicare standardized amounts and conversion factors of each setting. Medicare payments were converted to all-payer payment rates using a conversion factor. We assumed a successful primary or revision THA reduced direct medical costs related to symptomatic osteoarthritis by USD 590.

**Utilities**

We obtained utilities from Mota [29] for five of the health states in our study: (1) nonsurgery; (2) end-stage hip OA; (3) more severe OA; (4) successful post-THA; (5) post-first revision THA.

These utilities, synthesized by Mota [29] in a literature review, were based on studies researching individual patient data of quality of life with the EuroQol five-dimensional (EQ-5D) questionnaire. We calculated the utilities for the other two health states: (1) initial post-THA and (2) post-second THA revision. The utility of initial post-THA state was a combination of 25% of the pre-THA utility and 75% of post-THA utility. The utility of post-second THA revision was calculated based on the assumption that post-second THA revision utility could reach 90% of the utility for post-first THA revision (Table 1).

**Health State Transition and Transitional Probabilities**

The transition probabilities for the nonsurgical treatment arm were directly extracted from existing literature or statistics. Specifically, the transition probability from end-stage hip OA to more severe OA, and the probability of death at each cycle were extracted from Mota [29] and the US life tables [39], respectively.
The perioperative revision mortality probabilities were extracted from Mota [29], based on a literature review. Mota synthesized findings of US-based THA revision studies that involved large US patient databases—US Medicare claims and National Inpatient Sample, and risk adjustment by patient characteristics. For the perioperative THA mortality, we conducted a systematic literature review to obtain mortality rates for more granular age categories than the ones presented by Mota [29]. We used the risk-adjusted mortality rates reported by Memtsoudis et al. [27], which had the most granular age categorization based on our literature review (Table 1). Revision rates were obtained from the Australian Orthopaedic Association National Joint Replacement Registry [1](Table 1). We used the Australian joint replacement

| Parameter | Value | Source |
|-----------|-------|--------|
| Mortality | | |
| Natural death | Varies by age and gender | US Census Bureau Life Expectancy Table [39] |
| Perioperative THA death | Varies by age and gender | Memtsoudis et al. [27] |
| Perioperative revision death | Age < 75 years: 0.003; age ≥ 75 years: 0.012 | Mota [29] |
| Revision | | |
| Early aseptic first revision | Varies by age and gender | Australian Orthopaedic Association National Joint Replacement Registry [1]; Parvizi et al. [32] |
| Late aseptic first revision | Varies by age and gender | Australian Orthopaedic Association National Joint Replacement Registry [1]; Parvizi et al. [32] |
| Early aseptic second revision | 0.0583 | Australian Orthopaedic Association National Joint Replacement Registry [1]; Parvizi et al. [32] |
| Late aseptic second revision | 0.022 | Australian Orthopaedic Association National Joint Replacement Registry [1]; Parvizi et al. [32] |
| Early infection first revision | Varies by age and gender | Australian Orthopaedic Association National Joint Replacement Registry [1]; Parvizi et al. [32] |
| Late infection first revision | Varies by age and gender | Australian Orthopaedic Association National Joint Replacement Registry [1]; Parvizi et al. [32] |
| Early infection second revision | 0.017 | Australian Orthopaedic Association National Joint Replacement Registry [1]; Parvizi et al. [32] |
| Late infection second revision | 0.006 | Australian Orthopaedic Association National Joint Replacement Registry [1]; Lie et al. [23] |
| Transitional probability of nonoperative treatment to more severe OA | | |
| More severe OA | 0.041 | Mota [29] |
| Utility | | |
| End-stage hip OA | Varies by gender | Value for males: 0.52; for females: 0.47; Mota [29] |
| Nonsurgery | Varies by gender | Value for males: 0.52; for females: 0.47; Mota [29] |
| More severe OA | 0.28 | Mota [29] |
| Initial post-THA | 0.74 | Mota [29]; current authors’ calculation |
| Successful post-THA | Varies by gender | Values for males: 0.83; for females: 0.8; Mota [29] |
| Post-first revision THA (early and late) | 0.64 | Mota [29] |
| Post-second THA revision | 0.58 | Mota [29]; current authors’ calculation |
| Annual direct medical costs | | |
| End-stage OA/nonsurgery/more severe OA | USD 12,815 | Current authors’ calculation |
| Initial post-THA | USD 38,965 | Current authors’ calculation |
| Successful THA | USD 12,225 | Base value: medical cost of end-stage OA USD 590; current authors’ calculation |
| First aseptic revision THA (early and late) | USD 57,141 | Current authors’ calculation |
| First infection revision THA (early and late) | USD 95,763 | Current authors’ calculation |

OA = osteoarthritis.
registry because it was the only registry that contained OA-specific THA revision rates by age and gender. In addition to the Australian registry, we also searched the Swedish, Norwegian, and British registries. The US registry was launched in 2012, so it does not contain the late revision rates that we need for our model.

Early revision rates were modeled as revision surgery in the year after index THA, whereas late failure was modeled as revision surgery in subsequent years. We also differentiated between a patient’s first and subsequent revisions, and aseptic and infection revisions. The first-time aseptic revision rate was 6.69 times the first-time infection revision rate [1] and the second aseptic revision rate was 3.4 times the second infection revision rate [32]. We estimated the first revision rate by age weighted on the gender distribution of all patients who had THA in 2011.

Sensitivity Analysis

We conducted threshold analyses to identify the value of key parameters where net savings equal zero. In addition, we performed Monte Carlo analysis to evaluate: (1) the effect of uncertainty in the model assumptions regarding indirect cost benefits using probabilistic sensitivity analysis and (2) the effect of individual patient variability in age and gender using microsimulation.

Results

Expected Effect of THA on Patients’ Employment and Earnings

We estimated that THA increases the overall likelihood of employment by 18% (95% CI, 12%-23%). Our simulation found no difference in average annual earnings among workers who underwent THA relative to those who pursued nonsurgical management (mean change in earnings, USD 5073; 95% CI, USD −3188 to USD 13,387). Overall, we estimated that the average annual change in productivity, which reflected changes in the likelihood of employment and earnings, increased by USD 9503 for patients undergoing THA (95% CI, USD 1446–USD 17,812). We also estimated that THA reduces missed work days in a year by 36 days, from 50 to 14 missed work days (95% CI, 12–75 days). This estimate of missed work days did not incorporate missed work days to recover from THA, which we assumed was 40 days.

We estimated the effects of THA by age and gender (Table 2). The results showed changes in estimated annual earnings, value of missed work, and productivity for patients undergoing THA compared with nonsurgical treatment. The expected effects of THA on productivity ranged from USD 15,830 (males 40 to 49 years old) to USD 1917 (females 70 to 74 years old). The wide variation by age and, to a lesser extent, gender largely reflected differences in labor force participation rates (and likelihood of being employed) in these categories.

Cost-effectiveness of THA Relative to Nonsurgical Treatment

Using our Markov model, we estimated that mean lifetime direct cost for THA per patient was USD 30,365 higher than nonsurgical treatment (Table 3). The incremental direct costs associated with surgery were offset by USD 63,314 in indirect cost savings for a net societal savings of USD 32,948. Therefore, THA was a dominant treatment strategy relative to nonsurgical treatment because it resulted in overall cost savings with 5.5 more QALYs. Although the results showed net societal benefits from THA in the entire cohort, direct medical costs began to exceed indirect cost savings after patients were 64 years old. THA was cost-effective for all age groups at traditional willingness-to-pay thresholds, with the highest incremental cost per QALY gained at USD 10,748 for patients 75 years old or older.

The results showed that younger patients receiving THA accrued substantially higher lifetime savings because of the longer length of time in the workforce. The difference in indirect cost savings between the youngest group (40–49 years old) and patients between 70 and 74 years old was
USD 213,074 over a lifetime (Table 3). The average net societal savings for patients younger than 65 years was USD 97,892, while no societal savings were obtained for patients 65 years and older.

Sensitivity Analyses

We performed a threshold analysis to estimate the sensitivity of societal savings from THA to key model assumptions for patients 55 and 60 years old (Table 4). The results were robust to many of the model assumptions; we observed societal savings even after decreasing or increasing the base case assumptions (Table 4) by a factor of 10. With respect to productivity, the breakeven points for a female (male) 55 and 60 years old were 26% (20%) and 41% (28%) of base case assumptions (Table 1) (Appendix Table 3. Supplemental material is available with the online version of CORR®).

We used a Monte Carlo simulation to perform a probabilistic sensitivity analysis to assess the effect of parameter uncertainty in the indirect cost benefits. The mean lifetime cost for THA was USD 142,975 (95% CI, USD 141,960 –USD 143,990) and the mean cost of non-operative treatment was USD 177,875 (95% CI, USD 177,700–USD 178,051) for a mean net benefit of USD 34,900 (95% CI, USD 33,880–USD 35,920). For a typical patient in the US healthcare system, THA was the cost-saving strategy in more than 95% of trials (Fig. 2). The ellipse in that figure captured the 95% CI for the difference between the means of each strategy.

Discussion

Demand for THA among working-age patients has contributed to the growth in surgeries during the last decade. According to the Healthcare Cost and Utilization Project

| Table 3. Summary of the lifetime costs and savings from THA by age |
|---------------------------------|----------------|----------------|-----------------|-----------------|
| Age group | Incremental direct cost (A) (in USD) | Incremental indirect cost savings (B) (in USD) | Net societal savings (C) (in USD) | QALY gained (D) | ICER (C/D) |
| < 65 years | 28,067 | 125,958 | 97,892 | 7.0 | Dominant |
| 40–49 years | 28,905 | 218,738 | 189,833 | 8.3 | Dominant |
| 50–59 years | 28,128 | 136,023 | 107,894 | 7.1 | Dominant |
| 60–64 years | 27,564 | 65,659 | 38,095 | 6.0 | Dominant |
| ≥ 65 years | 32,323 | 10,052 | -22,271 | 4.2 | -5255 |
| 65–69 years | 30,147 | 28,157 | -1990 | 5.4 | -371 |
| 70–74 years | 30,162 | 5664 | -24,497 | 4.4 | -5618 |
| ≥ 75 years | 35,468 | 0 | -35,468 | 3.3 | -10,748 |
| All | 30,365 | 63,314 | 32,948 | 5.5 | Dominant |

ICER = incremental cost-effectiveness ratio; Net societal savings = Column B minus Column A; QALY = quality adjusted life year; weights by gender in age groups were calculated using 2011 National Inpatient Sample data.

| Table 4. Base case and threshold values for zero net societal savings |
|-----------------|----------------|----------------|-----------------|
| Parameter | Base case (male, female) | Age 55 years | Age 60 years |
|---------------------------------|----------------|----------------|-----------------|
| First aseptic revision rate (early) | 1.31%, 1.13% | Robust | Robust |
| First aseptic revision rate (late) | 0.61%, 0.63% | Robust | Robust |
| First infection revision rate (early) | 0.20%, 0.17% | Robust | Robust |
| First infection revision rate (late) | 0.09% | Robust | Robust |
| End-stage osteoarthritis [1] | USD 12,815 | Robust | Robust |
| Initial post-THA (365 days) | USD 38,965 | USD 123,700 (female) | USD 78,800 (female) |
| Productivity | Varies by age and gender | 26% of base (female) | 41% of base (female) |
| | | 20% of base (male) | 28% of base (male) |

Parameters are considered robust if net savings remain at 10 times the value of the base case; direct cost of end-stage osteoarthritis includes all medical costs, not just those associated with treatment of osteoarthritis.
Second, to estimate the post-THA productivity, the patient-reported outcome functionality data were collected retrospectively from patients up to 2 years after THA. Our sample was small and response rates were low (30%), which raises concerns regarding the generalizability of the findings. In addition, our retrospective approach introduces the possibility of recall bias regarding functional limitations before surgery. To assess potential recall bias, we compared baseline functional status values with published values [3, 14, 17, 31, 33]. Using a functional limitations index scale (ranging from 0 to 100, with higher values indicating greater function impairment), we found an average index score of 54 before THA based on our collected patient-reported outcome data. Our sample had similar preoperative function compared with those observed in previous studies, which ranged from 55 to 63 (of 100) in prospective studies using the WOMAC functional score [3, 14, 17, 31, 33]. Third, we assumed that the productivity of the nonsurgical group would be maintained at the presurgery values. Fourth, we used summary statistics from the Australian Joint Replacement Registry [1] to estimate the early and late revision rates. The revision rates from the Australian Orthopaedic Association National Joint Registry may serve as only a limited proxy for the US revision rates to the extent that patient demographic and clinical characteristics and joint replacement technologies differ between the two countries. Fifth, the economic and societal benefits of THA might be undervalued because we do not incorporate the value of nonpaid work, such as child care. Finally, our study focuses on the societal values of typical THAs performed in the inpatient setting.

In this study, we explored the effects of THA on employment, earnings, and missed work days and then assessed how these effects affect the measured cost-effectiveness of THA. We estimated increases in the likelihood of being employed (from 39% to 57%) and annual productivity (USD 9503). The study findings showed the importance of work-related benefits from THA. Conceptually, the potential effects of continued end-stage OA of the hip versus THA on workplace productivity seem clear. People with hip pain and associated functional limitations may be unable to work or may need to work a part-time or more limited schedule. Among people with end-stage OA who are able to maintain full-time employment, the effects on productivity have the potential to negatively influence their earnings. Empirical evidence on the effect of end-stage OA and THA on employment is limited, but generally supportive of the view that THA allows patients to maintain employment [4]. Numerous studies have shown that the majority of patients having THA return to work after the surgery [5, 10, 13, 30, 38]. For those returning to work, most do not encounter functional limitations in their ability to fully engage in work activities [30, 36].

The current study has several limitations. First, we inferred the effects of THA on employment, earnings, and missed work days by using the estimated relationship between functional limitations and economic outcomes for a sample of NHIS respondents and linking these estimates to patient-reported outcome for a sample that underwent THA. Although this technique followed prior research [11, 35], the method is based on the assumption that treatments only affect productivity through their impact on functionality. This approach takes the perspective of an average working patient and, thus, may not be applicable to patients in a specific occupation.
studies found that some patients who are out of work before surgery regained employment after THA [4, 28].

After incorporating the effects of THA on productivity, we showed a positive societal rate of return on healthcare spending for THA. We estimated that THA results in incremental direct costs of USD 30,365, which were offset by USD 63,314 in lifetime savings from increased productivity, for an average net societal savings of USD 32,948. We found that the estimated lifetime societal net benefit is comparable to that estimated for TKA (USD 32,948. We found that the estimated lifetime societal net productivity, for an average net societal savings of USD 32,948. We estimated THA results in a positive societal rate of return on healthcare spending for THA. We estimated that THA produces net societal savings of almost USD 10 billion from the more than 300,000 THAs performed in the United States each year. Our study concludes that THA produces net societal savings because of its effect on younger patients’ work status and earnings. Policy makers and payers should consider the indirect cost benefits of THA when assessing policies to control healthcare spending and improve quality. Given the positive return to society from spending on THA, as shown in our model results, policy proposals that discourage decisions to choose THA may be counterproductive.

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