A Cost-effectiveness Analysis of Total Hip Arthroplasty for Osteoarthritis of the Hip

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Objective.—To quantify the trade-off between the expected increased short- and long-term costs and the expected increase in quality-adjusted life expectancy (QALE) associated with total hip arthroplasty (THA) for persons with functionally significant hip osteoarthritis.

Design.—A cost-effectiveness study was performed from the societal perspective by constructing stochastic tree, decision analytic models designed to estimate lifetime functional outcomes and costs of THA and nonoperative managements.

Main Outcome Measures.—A modified four-state American College of Rheumatology functional status classification was used to measure effectiveness. These functional classes were assigned utility values to allow the relative effectiveness of THA to be expressed in quality-adjusted life years (QALYs). Lifetime costs included costs associated with primary and potential revision surgeries and long-term care costs associated with the functionally dependent class.

Data Used in the Cost-effectiveness Model.—Probability and incidence rate data were summarized from the literature. The THA hospital cost data were obtained from local teaching hospitals' cost accounting systems. Estimates of recurring medical costs for functionally significant hip osteoarthritis and for custodial care were derived from the literature.

Results.—The THA cost-effectiveness ratio increases with age and is higher for men than for women. In the base-case scenario for 60-year-old white women who have functionally significant but not dependent hip osteoarthritis, the model predicts that THA is cost saving because of the high costs of custodial care associated with dependency due to worsening hip osteoarthritis and that the procedure increases QALE by about 6.9 years. In the base-case scenario for men aged 85 years and older, the average lifetime cost associated with THA is $9100 more than nonoperative management, with an average increase in QALE of about 2 years. Thus, the THA cost-effectiveness ratio for men aged 85 years and older is $4600 per QALY gained, less than that of procedures intended to extend life such as coronary artery bypass surgery or renal dialysis. Worst-case analysis suggests that THA remains minimally cost-effective for this oldest age category ($80 000/QALY) even if probabilities, rates, utilities, costs, and the discount rate are simultaneously varied to extreme values that bias the analysis against surgery.

Conclusions.—For persons with hip osteoarthritis associated with significant functional limitation, THA can be cost saving or, at worst, cost-effective in improving QALE when both short- and long-term outcomes are considered. Further research is needed to determine whether this procedure is actually being used in this cost-effective manner, especially in older age categories.

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TOTAL HIP arthroplasty (THA) is commonly used to treat severe osteoarthritis of the hip. In 1990, an estimated 120 000 THAs were performed in North America, the majority of which were for patients with hip osteoarthritis.[1] While THA is generally regarded as an effective means of reducing the pain and functional limitation associated with severe hip osteoarthritis,[2] there is concern that a larger share of health care resources will be spent on THA in the future because of the increasing incidence of severe osteoarthritis of the hip, the growing demand for THA, and the high costs associated with this procedure.[3] The purpose of this article is to describe the structure and results of a decision analysis model of THA for patients with hip osteoarthritis that assesses the trade-off between the economic investment and improved quality of life associated with THA. The analysis should inform policymakers who wish to prioritize funding for health practices based on cost-effectiveness criteria.

Total hip arthroplasty is primarily done to improve quality of life rather than to extend it. Thus, any analysis of the cost-effectiveness of THA for hip osteoarthritis that allows for comparisons with other health practices must consider quality of life and not just quantity of life. The quality-adjusted life year (QALY) combines these two concepts and can be estimated to facilitate cost-effectiveness comparisons with other health practices. Despite the high use of THA, there are few formal cost-effectiveness analyses of THA for hip osteoarthritis that allow for such comparisons.[4,5] Furthermore, there are no analyses that consider long-term outcomes such as the need for revision surgery or custodial care costs associated with dependency due to worsening hip osteoarthritis. To address these issues, we constructed a decision analytic model of the short- and long-term consequences of THA and hip osteoarthri-

Table 1.—American College of Rheumatology Functional Classifications for Hip Osteoarthritis*

Class	Description
I	Complete ability to carry on all usual duties without handicaps
II	Adequate for normal activities despite handicap of discomfort or limited motion in the hip
III	Limited only to little or none of duties of usual occupation or self-care
IV	Incapacitated, largely or wholly bedridden or confined to wheelchair; little or no self-care

*From Steinbrocker et al.[6]

tis, estimated probabilities and rates required by the model by reviewing the literature, and assigned quality adjustments for various functional outcomes by a combination of primary utility assessment and literature review. Cost data were estimated using cost accounting systems of university-affiliated hospitals as well as the literature. The goal of this research is to compare the cost-effectiveness of THA for hip osteoarthritis with that of other health practices from the societal perspective.

METHODS

Outcomes

Functional outcome was considered the primary measure of effectiveness for THA. For modeling purposes, we adapted the four-state American College of Rheumatology (ACR) functional status classification for use in hip osteoarthritis (Table 1).[6] Pain is not explicitly modeled in this analysis because of its relatively subjective nature and because of the lack of data leading to valid long-term models. However, pain is considered in the analysis in that it has been found to be a major determinant of functional outcome in persons with arthritis. The goal of the decision analytic model was to estimate expected times in each ACR functional class and the direct medical costs attributable to hip osteoarthritis and its treatments for the rest of a person's life after a THA and to compare these outcomes with those associated with conservative nonoperative management. For the formal cost-effectiveness analysis, these functional classes were assigned utility values (quality adjustments) to allow the relative effectiveness of THA to be expressed in QALYs. All analyses pertain to patients in functional class III (significant functional limitation, but not dependent) deciding whether or not to undergo THA.

The direct medical costs associated with THA that were considered included acute hospital costs (inpatient bed, operating room, recovery room, prosthesis, diagnostic tests, transfusion services, rehabilitation, and medications), physician costs (surgeon, anesthesiologist, and consultants), and post–acute care rehabilitation costs. In addition, the physician, medication, and custodial care costs associated with functionally significant hip osteoarthritis were considered.

Models of Expected Outcomes

Decision analytic models of the THA and nonoperative strategies were constructed using the factored stochastic tree method described by Hazen.[7,8] Stochastic trees resemble decision trees in that chance nodes and decision nodes are incorporated. However, branches can represent not only instantaneous probabilistic events, such as the result of a THA or perioperative death, but also competing risks that can occur over the course of time, such as aseptic loosening, prosthetic infection, and death from other causes. Stochastic trees are similar to Markov chains in that mutually exclusive states must be identified. Rather than using the transition probabilities between states that drive Markov models, stochastic trees use transition rates between states, which allow for a continuous (rather than discrete) time representation. The continuous time nature of a stochastic tree allows for clear graphical representation of the modeled events and simpler computations. In addition, this approach allows for a complex problem to be disaggregated into factors that can be constructed separately but analyzed simultaneously, thus simplifying the modeling process without sacrificing the complexity of the model itself.

Figure 1 displays an abbreviated stochastic tree model for THA treatment. It begins with a probabilistic assessment of the primary procedure with the following possible short-term outcomes: (1) success, resulting in functional class I; (2) fair outcome, resulting in functional class II; (3) short-term failure, resulting in revision surgery within a year; and (4) death due to perioperative mortality. The long-term considerations are septic and aseptic failure (recurrent dislocation, prosthesis breakage, or loosening) and death from other causes. For example, a person who has had a THA success will live in functional class I until one of these three long-term events occurs. The analysis limits the number of revisions to three per lifetime.

The stochastic tree model that represents conservative treatment is depicted in Figure 2. The model for conservative treatment accounts for the worsening of functional status due to the natural history of hip osteoarthritis as well as death from unrelated causes.

Stochastic tree models, which are continuous-time based, can approximate the effect of discrete, time-dependent human mortality rates quite well, using their ability to depict any sum of exponentially distributed durations. To take advantage of this, we modeled mortality with an n-stage Coxian mortality model[9] (Figure 3). We calculated the best-fitting, age-, race-, and gender-specific Coxian mortality models[10] to US government life table data.[11] We found that a six-stage model provided the best fit for the age groups in this study.

Model Data

The probabilities and rates in our models include values that were obtained directly from published sources, derived from published data, or based on assumptions described herein. The literature was accessed via MEDLINE searches for the relevant data. Criteria for inclusion were publication date since 1986 (although relevant references to studies done prior to this date were also included) and whether the study used outcome measures and provided enough follow-up data that allowed for the estimation of the probabilities and rates needed in our analyses. Details of this second criterion are further explained herein.

Results relating to the short-term success of THA are frequently reported in the literature using the Harris hip score[12] or the Mayo hip score.[13] These scores were converted to the appropriate ACR functional status classes as shown in Table 2. These conversions are the consensus of three joint replacement orthopedic surgeons familiar with the ACR functional classification.

Model failure rate data were either obtained from published survival analyses or calculated by dividing the number of relevant events by the total number of patient-years over which the events occurred.

Efficacy of Primary and Revision THA and Operative Mortality.—For primary and revision THA, we derived probabilities from the reported data[13-16] (Table 3). However, no instances of death from the surgery were reported for the primary THA and the aseptic revision series. To incorporate the risk of surgical death into our model, we used the probability of surgical death as reported from other sources. White et al[17] report a mortality probability of 0.34% for 8859 patients with osteoarthritis who underwent first-time THA. Coventry et al[18] report a similar value (0.4%). For primary THA, we used the upper-bound mortality probability reported in the *Orthopedic Knowledge Update IV*[19] of 0.5%. Therefore, to obtain the model probability values, we renormalized the probability data to 99.5% (100%−0.5%) of their original values. For aseptic revision surgery, we used

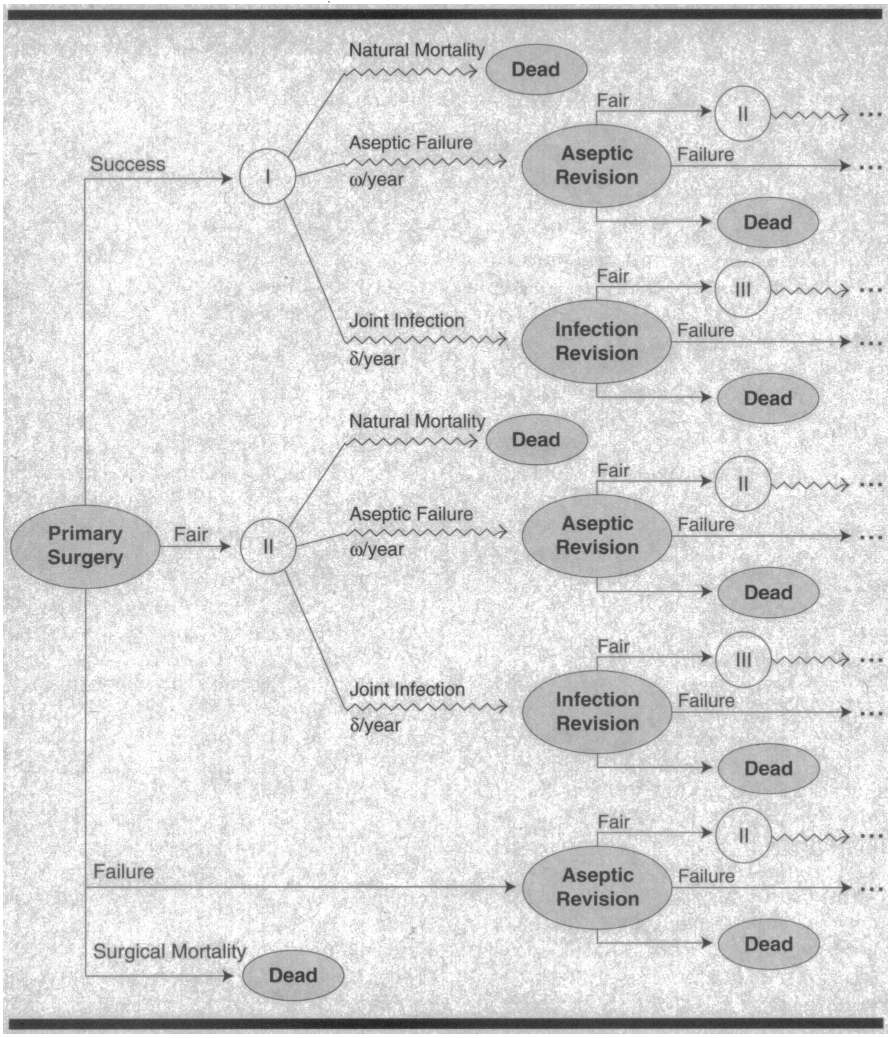

Figure 1.—An abbreviated stochastic tree for total hip arthroplasty (THA) surgery. The model begins on the left with a probabilistic assessment of the primary procedure with the following possible outcomes: (1) success, resulting in functional class I (functional class indicated in circles); (2) fair, resulting in functional class II; (3) short-term failure, resulting in revision surgery within a year; and (4) death due to perioperative mortality (see Table 4 for particular outcome probabilities). The success and fair branches of the tree then proceed with three independent stochastic branches, one leading to death from other causes (natural mortality) and the other two describing the longer-term risks of aseptic failure (recurrent dislocation, prosthesis breakage, or loosening) requiring revision and joint infection requiring revision. The wavy arrows indicate that these events occur over continuous time and are modeled using transition rates. The incidence of aseptic failure leading to revision surgery is denoted by ω, and δ represents the incidence of joint infection leading to revision surgery (see Table 5 for particular values of ω and δ; see Figure 3 for modeling of natural mortality). Thus, a person who has had a THA success will live in functional class I until one of these three events occurs. The aseptic failure revision and joint infection revision branches proceed similarly to the primary THA tree but have worse functional outcomes. The analysis limits the number of revisions to three per lifetime.

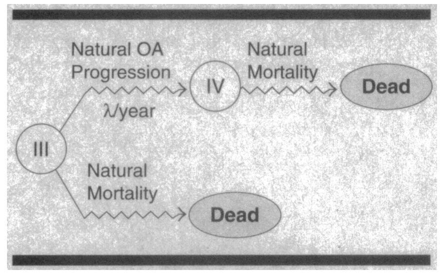

Figure 2.—Conservative management of osteoarthritis (OA) of the hip. The incidence of progression from functional class III to functional class IV is denoted by λ.

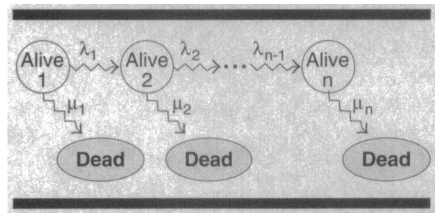

Figure 3.—Coxian n-stage mortality factor. The successive "Alive" stages can be viewed as life stages, each with its own appropriate death rate. Parameters λ_i, μ_i, and the number of stages (n) can be chosen so as to accurately approximate human survival distributions.

Table 2.—American College of Rheumatology (ACR) Functional Class Conversion

ACR Class*	Harris Hip Score†	Mayo Hip Score‡	Mayo Hip Score§
I	90-100	90-100	70-80
II	70-89	70-89	60-69
III	40-69	40-69	30-59
IV	<40	<40	<30

*From Steinbrocker et al[6] (1949).

†From Harris[12] (1969). Reflects entire scale (pain, function, range of motion, and absence of deformity).

‡From Kavanagh and Fitzgerald[13] (1985). Reflects entire scale (pain, function, mobility and muscle power, and roentgenographic assessment).

§From Kavanagh et al[14] (1989). Reflects clinical portion of the scale (pain, function, and mobility and muscle power).

the perioperative mortality probability reported by Booth et al[20] of 1.2%. Under the assumption that this probability is representative over all aseptic revisions, we installed this probability for each type of surgery and recalculated the probabilities of the other possible outcomes as 98.8% (100%−1.2%) of their originally reported values (Table 4).

Long-term Infection Failure Rates.— Annual incidence rates of long-term failure attributable to deep infection following primary THA are reported in the literature to be less than 0.25%.[14,21-25] In our base-case model, we used an annual infection rate following initial THA surgery of 0.002 infection per person-year.

Incidence of infection following revision surgery has been reported to be as high as 0.117 infection per patient-year,[26] but has more typically ranged between 0.005 and 0.045 infection per patient-year.[27-32] Recent studies have reported incidence rates less than 0.005 infection per patient-year.[25,33-35] For first revision procedures in our model, we used a rate of 0.02 infection per patient-year.

We calculated a yearly infection rate following third revisions using data from Kavanagh and Fitzgerald.[15] These authors report a single instance of sepsis from a sample of seven third revisions. Using the reported average time to follow-up of 2.833 years to estimate the time of occurrence (1/[7×2.833]), there were 0.050 infection per person-year.

Kavanagh and Fitzgerald[15] also report infection failure results for second revision surgeries. From 45 cases, the authors report two instances of sepsis with a mean follow-up time of 3.417 years, which yields a failure rate of 0.013 infection per person-year. However, it is counterintuitive to have infection rates for second (or third) revisions that are lower than infection rates for first revisions. To reflect expert opinion and make any error in modeling bias against the surgery, we used a value of 0.035 infection per person-year for the infection rate for second revisions. This value was obtained by averaging the infection rates for first and third revisions.

Sanzen et al[16] report results that yield an estimated value for infection failure following revision surgery for an infected THA of 0.0063 infection per person-year. However, in our model, use of an infec-

Table 3.—Number of Reported Surgical Results for Primary and Revision THA*

Reference	Surgery	Total	ACR Functional Class I	II	III	IV	Death
Kavanagh et al[14] (1989)	Primary THA—Harris score	296	206	77	13	0	0
	Primary THA—Mayo score	315	243	53	19	0	0
Kavanagh and Fitzgerald[13] (1985)	Revision 1	164	0	116	48	0	0
Kavanagh and Fitzgerald[15] (1987)	Revision 2	45	0	29	16	0	0
Kavanagh and Fitzgerald[15] (1987)	Revision 3	7	0	6	1	0	0
Sanzen et al[16] (1981)	Infection	104	0	0	80	22	2

*THA indicates total hip arthroplasty; ACR, American College of Rheumatology.

Table 4.—Model Surgical Probabilities for Primary and Revision THA Outcome*

Surgery	Initial ACR Class	ACR Class Outcomes I (Success)	II (Fair)	III (Failure)	IV	Death (Surgical Mortality)
Initial THA†	III	0.6925	0.2430	0.0600	0	0.0050
Aseptic Revision 1‡ (no septic history)	III	0	0.7015	0.2865	0	0.0120
Revision 1‡ (septic history)	IV	0	0	0.7015	0.2865	0.0120
Revision 2§ (no septic history)	III	0	0.6363	0.3517	0	0.0120
Revision 2§ (septic history)	IV	0	0	0.6363	0.3517	0.0120
Revision 3§ (no septic history)	III	0	0.8477	0.1403	0	0.0120
Infection Revision‖	IV	0	0	0.7692	0.2115	0.0193

*THA indicates total hip arthroplasty; ACR, American College of Rheumatology.
†Derived from Kavanagh et al[14] (1989) and the *Orthopedic Knowledge Update IV*[19] (1992).
‡Derived from Kavanagh and Fitzgerald[13] (1985).
§Derived from Kavanagh and Fitzgerald[15] (1987).
‖From Sanzen et al[16] (1988).

Table 5.—Model Yearly Revision Rates per Person-Year Following Total Hip Arthroplasty (THA)*

Surgery	Aseptic Failure Rate (ω)	Infection Failure Rate (δ)
Initial THA	0.01	0.002
Aseptic revision 1	0.04	0.02
Aseptic revision 2	0.05	0.035
Aseptic revision 3	0.10	0.05
Infection revision 1	0.04	0.02
Infection revision 2	0.05	0.035
Infection revision 3	0.10	0.05

*ω and δ indicate values to be applied to the model in Figure 1.

tion failure rate following revision surgery for an infected THA that is much smaller than the post–aseptic revision surgery infection failure rate was rejected as unrealistic. We assigned the same infection failure rate values for postinfection revisions as we used for post–aseptic revisions.

Long-term Aseptic Failure Rates.—In general, reported annual incidence rates of THA revisions due to aseptic loosening of the primary THA range from 0.2% to nearly 2%.[14,23,24,36-45] We used an aseptic failure rate of 0.01 failure per person-year in our model's base case.

To model the aseptic failure rate following first revision surgeries, we assigned a value of 0.04 failure per person-year. We based this figure on published data for which this failure rate ranges from less than 1% to more than 22%.[26,28,32,34,46-52]

Aseptic revision rates following multiple revisions were based on data from Kavanagh and Fitzgerald.[15] For second revisions, there was an aseptic failure rate of 0.046 failure per person year. We used a value of 0.05 failure per person-year in our model. For third revisions, the aseptic failure rate was 0.10 failure per person-year, which we used as the model value.

We modeled the yearly aseptic failure rates for infection revision surgeries and aseptic revision surgeries with the same values. This is based on findings from a review of the literature by James et al,[53] who found similar loosening rates in hips revised for septic and aseptic failures.

Table 5 presents the summary transition rate data for aseptic and infection revision surgeries.

Natural Progression of Functional Class III Hip Osteoarthritis.—In work done in the late 1950s and early 1960s, Danielsson[54] reports on the progression of functional deterioration of patients with hip osteoarthritis over a 10-year follow-up period. One third of 91 patients progressed to a point of severe restriction of function (ie, where the patient needs the assistance of other people for day-to-day existence). Assuming a constant yearly rate of natural progression of osteoarthritis of the hip yields a model value of 0.0333 transition per person-year.

Estimates of Utilities Associated With ACR Functional Classes

A continuous risk utility assessment, developed by Pellissier and Hazen,[55] was used to elicit quality adjustments (utility) for functional classes II, III, and IV. We assigned functional class I a utility of 1 and death a utility of 0. The assessments were modifications of standard gamble questions. Based on a sampling of 45 utility assessments of healthy adults aged 22 to 62 years, we assigned the following quality adjustments to each ACR functional class: for class I, 1.0; for class II, 0.8; for class III, 0.5; and for class IV, 0.3. These utilities represent approximately the median values elicited from this sample.

Other investigations that have measured actual patient utility before and after THA indicate that the utility estimates are reasonable. Laupacis and colleagues[56] measured patient utility in 188 Canadian patients using the time–trade-off method and found that the mean preoperative utility was approximately 0.3. Katz and colleagues[57] used a modified time–trade-off method to estimate patient utility in 54 Massachusetts patients and found the mean preoperative utility to be approximately 0.7. Thus, the utility assigned to ACR functional class III (0.5), which was used as a preoperative utility in our model, is within the range of the empirical studies that were available to us in the literature. Note also that the published studies on preoperative utility did take pain into consideration, indicating that our direct estimate of utility for ACR functional class III is valid even though pain was not explicitly included in the utility assessment.

Estimates of Costs

We recognize the methodologic challenges of assigning costs to the THA and nonoperative strategies. We rejected using charges (either published or available locally) because the charge/cost ratios may be different for services, medications, and equipment for the operative strategy compared with the nonoperative strategy. Developments in hospital cost accounting systems provide a better although still imperfect means of estimating true costs of services, medications, and equipment rendered in a hospital.

There are two published estimates of THA costs in the literature. Barber and Healy[58] reported on the experience of 104 patients with elective THAs done in

1990 at the Lahey Clinic in Massachusetts. They noted that the average hospital cost was $12 348. However, this estimate was derived by transforming charge data to costs using a standard cost/charge ratio, which does not eliminate the accuracy concerns of using charge data. In addition, they did not report on physician costs or the costs of post–acute care hospital rehabilitation. Laupacis and colleagues[5] reported that the average cost for 60 patients who underwent elective THA in Canada was $11 127 (1988 Canadian dollars).

To better estimate the true total cost of THA as performed in the 1990s in the United States, we used our local university-affiliated hospital's cost accounting system, which had actual cost data on 149 primary unilateral THAs and 47 unilateral revision THAs done in 1992, to estimate hospital cost per case. Medicare reimbursement was used as a proxy for physician costs. Rehabilitation costs were estimated by taking a weighted average of estimated costs of home health rehabilitation and inpatient rehabilitation, where the weights were determined by the proportions of patients actually receiving home health or inpatient rehabilitation in 1992, and the costs were derived from cost accounting systems for the university-affiliated hospital's home health agency and the university-affiliated acute rehabilitation hospital. We believe that this approach to estimating costs allows us to compare our derived cost-effectiveness ratio for THA with those of other procedures reported in the literature.

An estimate of recurrent direct medical costs associated with treatment for ACR functional classes III and IV was also made, using empirical data collected by Liang and colleagues.[4] They found the mean charge for physician and allied health professional visits, tests, medications, and devices for the 6 months prior to THA was $343 (1982 dollars). We have annualized 80% of this amount (as an estimate of the cost/charge ratio) and adjusted this to 1991 dollars using the consumer price index.[59]

Finally, we estimated the custodial care costs associated with dependency on others for self-care attributable to worsening hip osteoarthritis (class IV). This care could be rendered at home by a 24-hour caregiving arrangement or in a nursing home. We used the average annual reimbursement for a nursing home in the United States, which is approximately $35 000 per year,[60] as the cost of custodial care for those with functional class IV hip osteoarthritis. A summary of our base-case economic assumptions is shown in Table 6. In our base-case analysis, future costs were discounted at an annual rate of 3%.

Table 6.—Costs Associated With the Total Hip Arthroplasty (THA) Decision (1991 Dollars)

Cost	No THA	Primary THA	Revision
Hospital cost per case	0	17 000	20 000
Physician reimbursement per case	0	5000	5000
Rehabilitation cost per case	0	3000	3000
Medical costs per year for ACR class III and IV*	775	775	775
Custodial care costs per year for ACR class IV	35 000	35 000	35 000

*Includes physician, allied health professionals, tests, medications, and devices. ACR indicates American College of Rheumatology.

Analysis

Average time spent in each functional class and average discounted lifetime costs were computed for the THA and the nonoperative strategies. Discounted quality-adjusted life expectancy (QALE) was calculated using utilities assigned to each functional class and discounting future QALYs by 3% per year. The marginal cost-effectiveness ratio was calculated by dividing the difference in discounted lifetime costs between the THA and conservative strategies by the difference in discounted QALEs.

Separate analyses were done for women and men in each of four age categories: age 60 years, age 70 years, age 80 years, and ages 85 years and older. For each of these eight categories, a best-estimate base case was considered using the values for probabilities, rates, utilities, costs, and the discount rate described herein. In addition, worst-case scenarios were considered by simultaneously increasing operative death and failure probabilities by 100%, changing the proportion of success to fair outcomes after primary THA from 2/1 to 1/2, increasing the surgical revision rates by 100%, reducing the rate of osteoarthritis progression by 50%, changing the utilites of functional classes III and IV from 0.5 and 0.3 to 0.7 and 0.5, respectively, increasing the cost of THA by 25%, reducing the medical and custodial care costs associated with functional classes III and IV hip osteoarthritis by 25%, and increasing the discount rates for future QALYs and costs from 3% to 8% per year. These worst-case analyses were done to assess the sensitivity of the cost-effectiveness ratios given the uncertainty of the base-case probability and rate estimates. They provide a conservative boundary to the estimates of the age- and sex-specific THA cost-effectiveness ratios.

All calculations were performed using stochastic tree algorithms developed by Hazen et al[7] implemented on a microcomputer using Microsoft EXCEL 5.0 (Microsoft Corp, Redmond, Wash).

RESULTS

Table 7 shows the outcome and cost-effectiveness results for the two extreme categories that were analyzed, white women aged 60 years and white men aged 85 years or more. If conservative management is chosen, the best-estimate base-case model predicts that 60-year-old women will on average spend slightly less than 15 additional years in functional class III and then slightly less than the

Table 7.—Outcome and Cost-effectiveness Results for Base-Case and Worst-Case Scenarios for Two Examples of Extreme Demographic Categories*

	White Women Aged 60 y				White Men Aged ≥ 85 y			
	Base Case		Worst Case		Base Case		Worst Case	
Result	THA	No THA	THA	No THA	THA	No THA	THA	No THA
Expected years in ACR class I	13.27	0	4.79	0	3.36	0	1.34	0
Expected years in ACR class II	7.13	0	11.56	0	1.59	0	3.19	0
Expected years in ACR class III	1.38	14.88	3.52	18.10	0.09	4.47	0.34	4.76
Expected years in ACR class IV	0.60	7.73	1.98	4.51	0.02	0.63	0.12	0.34
Life expectancy, y	22.38	22.61	21.85	22.61	5.06	5.10	4.99	5.10
QALY†	13.70	6.82	7.63	6.43	4.16	2.16	3.13	2.61
Expected cost, $ ‡	47 649	165 440	68 478	38 499	30 580	21 432	48 265	7338
Marginal cost-effectiveness ratio, $ §	(17 115)		27 441		4575		79 029	

*THA indicates total hip arthroplasty; ACR, American College of Rheumatology; and QALY, quality-adjusted life year.
†QALY discounted at 5% for base case and 8% for worst case.
‡Expected costs discounted at 5% for base case and 8% for worst case.
§Marginal cost-effectiveness ratio (additional $ per additional QALY).

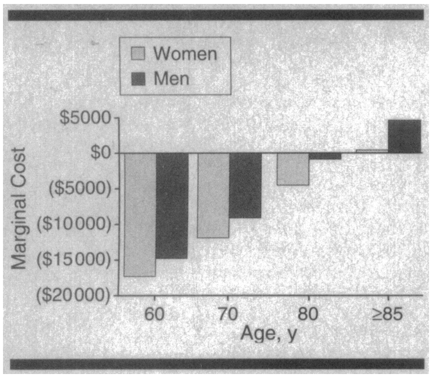

Figure 4.—Total hip arthroplasty (THA) marginal cost per quality-adjusted life year gained, base-case scenario.

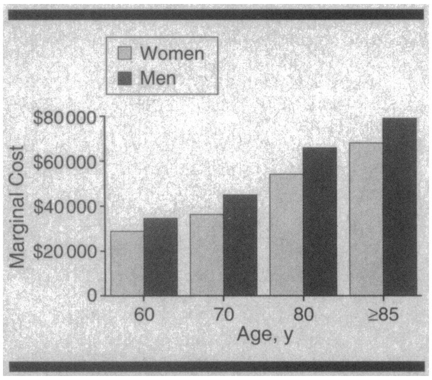

Figure 5.—Total hip arthroplasty (THA) marginal cost per quality-adjusted life year gained, worst-case scenario.

Table 8.—Cost-effectiveness Ratio Estimates of THA and Other Procedures*

Procedure	Additional Cost, $†
THA (lifetime estimate)	
60-year-old white woman	Cost saving
≥85-year-old white man	6100/QALY
Low-dose zidovudine therapy for asymptomatic HIV infection—continuous effect[66]	7800/LY
Coronary artery bypass, left main disease plus angina[59]	8100/QALY
THA (first 3 y following surgery)[4]	8700/QALY
Hydrochlorothiazide for hypertension[61]	24900/LY
Screening mammography, women ≥ 50 y[62]	20000 to 50000/LY
Coronary artery bypass, two-vessel disease plus angina[59]	37400/QALY
Renal dialysis, in-center benefit, men[60]	59400 to 68300/LY
Low-dose zidovudine therapy for asymptomatic HIV—one-time effect[66]	83600/LY
Cholestyramine for high cholesterol[63]	91200/LY
Captopril for hypertension[61]	98100/LY
Autologous blood donations for elective THA[65]	218800/QALY
Screening mammography, women < 50 y[64]	220400/LY

*THA indicates total hip arthroplasty; QALY, quality-adjusted life year; LY, life year; and HIV, human immunodeficiency virus.

†Data as reported in the medical literature, adjusted to 1991 US dollars using the medical component of the consumer price index.[57]

last 8 years of their life in functional class IV before dying. For similar persons opting for THA, the expected time spent in improved functional classes I and II is about 20 years, while an average of about 2 years is spent in functional classes III and IV. The slightly lower life expectancy predicted after THA is related to the small but finite mortality associated with the primary and revision surgeries. The higher QALE associated with THA is related to the higher utility values assigned to functional classes I and II compared with those assigned to classes III and IV. Thus, for 60-year-old white women undergoing THA for functional class III hip osteoarthritis, the average discounted increase in QALE is about 6.9 years compared with nonoperative management. The average discounted lifetime cost associated with the THA strategy is $117000 less than the nonoperative management because of the high costs of custodial care associated with dependency due to worsening hip osteoarthritis. The mean number of operations that the decision analytic model predicted for those opting for THA was 1.59. Our best-estimate base-case model predicts that THA is cost saving for a 60-year-old white woman with hip osteoarthritis in functional class III when compared with conservative management.

The best-estimate base-case model predicts that white men aged 85 years or more who choose THA will increase their discounted QALE by 2 years compared with conservative management. This is associated with an increase in discounted lifetime cost of slightly more than $9100. Thus, the cost-effectiveness of THA compared with conservative management is about $4600 per QALY gained.

Table 7 also shows the results of the worst-case analyses for the two extreme categories. The worst-case model for 60-year-old white women projects that THA is not cost saving and that the marginal cost-effectiveness ratio of THA is $27000 per QALY gained. For white men aged 85 years or more, the worst-case cost-effectiveness ratio is nearly $80000 per QALY. Figures 4 and 5 show the best-estimate base-case and worst-case cost-effectiveness ratio results for all eight categories considered.

Total hip arthroplasty appears to be an efficient means of extending one's QALE compared with other expensive but commonly used technologies, even if the most conservative worst-case scenarios are considered.[63-68] Table 8 lists the marginal cost-effectiveness ratios (adjusted to 1991 dollars) of other health practices, including coronary artery bypass surgery[61] and renal dialysis.[62] Furthermore, there are many instances when THA may reduce societal lifetime costs as well as increase QALYs for those with functionally significant hip osteoarthritis.

COMMENT

The results of these analyses show that if THA is used as a treatment for hip osteoarthritis associated with significant functional limitation, the procedure appears to be cost saving or, at worst, relatively cost-effective given reasonable variations in age, sex, probabilities of initial THA success and mortality, long-term rates of failure, rate of osteoarthritis progression, utility values of ACR functional classes III and IV, surgical, medical, and custodial costs, and discount rate. The cost-effectiveness of THA in terms of additional dollars spent per QALY gained is similar to or better than that of coronary artery bypass surgery and renal dialysis, two widely accepted and costly technologies that extend life.

The first cost-effectiveness analysis of total joint arthroplasty was reported by Liang and colleagues in 1986.[4] This was a prospective study of 23 patients who underwent THA and 22 patients who had total knee replacement surgery, all of whom were followed up for 6 months. The cost-effectiveness results were reported as mean number of 0.01 unit of improvement on the Bush Index of Well-being[69] scale per $1000 marginal cost. While the analysis determined for which patients THA was most cost-effective, comparison could not be made with other health practices, and long-term analyses were not done. A more recent cost-effectiveness analysis was performed by Laupacis and colleagues.[5] This was an empirical study done in Canada in which cost and utility data were collected over a 1-year follow-up period. They estimated the marginal cost-effectiveness ratio for the first 3 years following THA to be $8731 per QALY gained, indicating that THA is very cost-effective. Again, no long-term estimates were provided.

A major long-term clinical and economic concern after THA has been the need to perform revision surgery for septic or aseptic loosening. This has been particularly true for the "young old" (ie, those aged 55 to 65 years who have a life expectancy of 20 years or more). Obviously, revision surgery adds considerable lifetime cost to those who require it and should be considered in a cost-effectiveness study of primary THA. We explicitly modeled the need for at least three revisions and recognized that the functional outcomes of revision surgery are inferior to those of primary surgery.

The major long-term clinical and economic concern of nonoperative treatment for functionally significant hip osteoarthritis is the progression of the disease and the possibility of worsening functional limitation and the need for long-term care. Our model estimated the effect of both the rate of progression of hip osteoarthritis and the costs of long-term care on the cost-effectiveness of THA.

Our study introduces the use of transition rates to model THA failure, the progression of osteoarthritis, and death from other causes. This allowed us to estimate the expected time spent in each of the ACR functional classes for the rest of a person's life, which we transformed into a QALE. We believe that these methodologic enhancements together with the consideration of long-term outcomes allow our model to more closely reflect the actual effectiveness and costs associated with THA decision making than previous studies in a way that allows comparisons with other health practices.

We were able to access relevant data from the literature for all probabilities, transition rates, and utilities that were required by the model. However, some rates were based on few data and some simplifying assumptions were made when the data were sparse or when the presentation of the data prohibited more sophisticated estimates. Other rates were addressed by several relevant articles, but recategorization of the data had to be performed (eg, the probabilities of surgical success [functional class I and II outcomes] and perioperative failure [functional class III and IV outcomes]). While these concerns potentially could affect the validity of our study, the worst-case analyses performed indicate that the cost-effectiveness of THA remains quite favorable when compared with other costly health practices despite simultaneous variations in the relevant probabilities, rates, utilities, costs, and discount rate.

It is likely that some of our simplifying assumptions resulted in an underestimate of the effectiveness of THA. Although a number of recent innovations have worse outcomes than the traditional operations, THA outcomes and failure rates may be improving over time. Thus, current outcomes and failure rates may be better than the base-case estimates we made based on operations that were done 10 to 15 years ago. In addition, we did not allow revision surgery to result in a functional class I outcome. Similarly, we did not model the increase in life expectancy associated with THA, which has been observed by some investigators.[70] There is likely to be an increased mortality rate associated with functional class IV (profound functional limitation) hip osteoarthritis that we did not take into consideration. Finally, the assumption that revision rates were constant over time probably biases our base-case estimates of cost-effectiveness against surgery. Given the fact that future costs and QALYs were discounted, the overestimation of revision surgeries in the short run penalizes the THA strategy in terms of cost as well as effectiveness. In summary, even our base-case estimates of THA cost-effectiveness should be considered as conservative.

Although the cost-effectiveness of THA is generally reasonable, there are certain older age categories where the worst-case analysis indicates that the resources needed to improve QALE may exceed those available. Further age- and sex-specific probability, rate, utility, and cost data are needed to reduce the uncertainty of THA cost-effectiveness, especially in the oldest age categories.

Finally, these analyses do not address whether resources allocated to the current use of THA in this country are being used efficiently. This will require further empirical study. We have cited examples of potential variance in practice. The mean preoperative utility before THA was 0.3 in a study done in Canada and 0.7 in a study done in Massachusetts. The difference may be attributable to methodologic variance, but another viable hypothesis is that surgeons in this country may operate on patients who are less functionally limited than those being operated on by Canadian surgeons. We were unable to determine the cost-effectiveness of THA for functional class II hip osteoarthritis because of the lack of data on the progression of milder forms of hip osteoarthritis. Further work is needed in this area to more precisely determine reasonable guidelines for the cost-effective use of this procedure.

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