Cost-Effectiveness of Transcatheter Aortic Valve Replacement Compared With Standard Care Among Inoperable Patients With Severe Aortic Stenosis

Results From the Placement of Aortic Transcatheter Valves (PARTNER) Trial (Cohort B)

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Background—In patients with severe aortic stenosis who cannot have surgery, transcatheter aortic valve replacement (TAVR) has been shown to improve survival and quality of life compared with standard therapy, but the costs and cost-effectiveness of this strategy are not yet known.

Methods and Results—The PARTNER trial randomized patients with symptomatic, severe aortic stenosis who were not candidates for surgery to TAVR (n=1179) or standard therapy (n=1179). Empirical data regarding survival, quality of life, medical resource use, and hospital costs were collected during the trial and used to project life expectancy, quality-adjusted life expectancy, and lifetime medical care costs to estimate the incremental cost-effectiveness of TAVR from a US perspective. For patients treated with TAVR, mean costs for the initial procedure and hospitalization were $42,806 and $78,542, respectively. Follow-up costs through 12 months were lower with TAVR ($29,289 versus $53,621) because of reduced hospitalization rates, but cumulative 1-year costs remained higher ($106,076 versus $53,621). We projected that over a patient’s lifetime, TAVR would increase discounted life expectancy by 1.6 years (1.3 quality-adjusted life-years) at an incremental cost of $79,837. The incremental cost-effectiveness ratio for TAVR was thus estimated at $50,200 per year of life gained or $61,889 per quality-adjusted life-year gained. These results were stable across a broad range of uncertainty and sensitivity analyses.

Conclusions—For patients with severe aortic stenosis who are not candidates for surgery, TAVR increases life expectancy at an incremental cost per life-year gained well within accepted values for commonly used cardiovascular technologies.

Clinical Trial Registration—URL: http://www.clinicaltrials.gov. Unique identifier: NCT00530894.

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Key Words: aortic stenosis ■ transcatheter valve therapy ■ cost-effectiveness ■ clinical trials

Valvular aortic stenosis occurs most commonly among the elderly and, in the absence of definitive treatment, leads to progressive symptoms, functional decline, and death.1,2 Nonetheless, many patients with severe aortic stenosis do not undergo surgical valve replacement because of both cardiovascular and noncardiovascular comorbidities that result in unacceptable surgical risk.3-5 Recently, thePlacement of Aortic Transcatheter Valves (PARTNER) trial reported that in a cohort of patients who were unsuitable for surgical valve replacement (cohort B), transcatheter aortic valve replacement (TAVR), compared with standard nonsurgical care, resulted in a 20% reduction in mortality at 12 months, as well as improved functional status and a reduction in hospital admissions for aortic stenosis.6

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New technologies are often cited as a major contributor to increasing healthcare costs.7 Before a new technology or...
clinical strategy is widely adopted, it is therefore important to understand the clinical and economic benefits that any increased up-front expenditures may yield. Given the advanced age and multiple comorbid conditions that characterize patients with high surgical risk for surgical valve replacement, the question of whether TAVR can provide meaningful health benefits to the population at an acceptable cost is particularly germane. To address these questions, we conducted a pre-planned health economic study alongside the PARTNER trial, with the goal of understanding the incremental costs and cost-effectiveness of TAVR compared with standard therapy among inoperable patients with severe aortic stenosis.

Methods

Study Population

One-year clinical results from the PARTNER trial (cohort B) have been published previously.4 Briefly, the trial enrolled adults with severe aortic stenosis, New York Heart Association functional class ≥2, and high surgical risk based on the Society for Thoracic Surgeons risk score5 or other anatomic or technical factors. These patients were determined not to be suitable surgical candidates on the basis of evaluation by at least 2 surgical investigators and the trial’s executive committee. Patients were randomized to TAVR via the transfemoral route (n = 179) or standard nonsurgical therapy (n = 179), which could include balloon aortic valvuloplasty at the discretion of the treating physician. The study was approved by each enrolling center’s institutional review board, and all patients provided written informed consent. Of the 358 randomized patients, 234 (65%) enrolled at 17 US centers additionally consented to the collection of hospital billing data.

Analytic Overview

All randomized subjects were included in the present study and analyzed according to intention to treat. Our analysis was performed from the perspective of the US healthcare system (ie, a modified societal perspective) and consisted of 2 main components. Data on survival, quality of life, healthcare resource use, and hospital charges were collected through the first 12 months of follow-up (the minimum follow-up duration for the trial) for all patients and were used to calculate survival, quality-adjusted survival, and costs for the trial period. The empirical 12-month data for costs and quality of life, along with all of the available data on survival (up to a maximum of 30 months), were used to project outcomes beyond the trial, from which estimates of life-years, quality-adjusted life-years (QALYs), and lifetime costs were developed for each patient who survived the trial period. These estimates were then aggregated to calculate average costs and benefits (and their associated distributions) at the treatment-group level.

Determination of Medical Care Costs

Medical care costs were assessed from the perspective of the US healthcare system by use of a combination of resource-based accounting and hospital billing data, as described previously,6,7 and are reported in 2010 US dollars. Costs from years before 2010 were converted to 2010 dollars with the medical care component of the CPI-U. Costs from years before 2010 were converted to costs using national average per diem rates for residents of each enrolling hospital’s Medicare cost report.8 When bills were unavailable (generally because of admission to nonstudy hospitals or to hospitals that do not produce standard billing data), diagnosis, procedure, and adverse event information from the study database were used to assign each admission to a unique Medicare Severity-Adjusted Diagnosis Related Group (MS-DRG). Average reimbursements for each respective MS-DRG, based on 2008 Medicare Provider Analysis and Review (MedPAR) data,9 were used as the proxy for admission costs in these cases.

Other Hospital Costs

For the initial TAVR procedure, study sites recorded procedure duration and counts of major items consumed, such as support wires, guiding catheters, valvuloplasty balloons, Edwards SAPIEN valve systems, temporary pacing catheters, and vascular closure devices. Costs for each procedure were calculated by multiplying item counts by their respective unit prices, determined by the average acquisition costs at a sample of US hospitals. An estimated US commercial price for the Edwards SAPIEN valve system of $30 000 was used for the primary analysis.

Other Costs

Data on rehabilitation facility stays, nursing home stays, and outpatient resource use (emergency room visits, physician office visits, outpatient cardiac testing) were collected by the enrolling sites at each study follow-up visit. These measures of resource use were converted to costs using national average per diem rates for residential care and Medicare reimbursement rates for outpatient care based on the Medicare Fee Schedule.

Cost-Effectiveness Analysis

We evaluated cost-effectiveness over a lifetime horizon in terms of both cost per year of life gained (primary analysis) and cost per QALY gained (secondary analysis). These analyses required the projection of life expectancy, quality-adjusted life expectancy, and costs over the anticipated life expectancy of each patient who remained alive at the completion of the trial.

Life Expectancy Estimation

Survival analyses were performed with a locked data set as of September 28, 2010, with a minimum follow-up duration of 12 months, a maximum follow-up duration of 30 months, and mean follow-up duration among survivors of 18 months. To estimate life expectancy for each surviving patient, we used parametric survival models to extrapolate survival probabilities beyond the follow-up time of the trial.

Other Index Hospital Costs

Costs for the remainder of each initial hospital stay for TAVR were derived from hospital bills, which were available for 121 of the 175 patients who underwent an attempted TAVR procedure (97% of patients who agreed to participate in data collection from 16 US study hospitals). After the exclusion of charges for care received before randomization and charges for the index TAVR procedure itself, all remaining hospital charges were converted to costs by use of cost-center-specific cost-to-charge ratios obtained from each enrolling hospital’s Medicare cost report.10 When bills were unavailable, the costs of hospital care were estimated with a linear regression model derived from the patients with complete billing data (model R²=0.84). Covariates included in the model included total intensive care unit (ICU) and non-ICU length of stay, in-hospital death, in-hospital acute renal failure, and major vascular complication. Use of alternative models, including linear regression of log-transformed costs (with retransformation to natural units), yielded results that were virtually identical.

Follow-Up Hospital Care

Sites collected information on follow-up hospital admissions for any cause at scheduled follow-up visits (1, 6, and 12 months) and on learning of adverse events. Costs for subsequent hospital admissions were calculated from billing data with hospital and cost-center-specific cost-to-charge ratios when bills were available (54% of admissions). When bills were not available (generally because of admission to nonstudy hospitals or to hospitals that do not produce standard billing data), diagnosis, procedure, and adverse event information from the study database were used to assign each admission to a unique Medicare Severity-Adjusted Diagnosis Related Group (MS-DRG). Average reimbursements for each respective MS-DRG, based on 2008 Medicare Provider Analysis and Review (MedPAR) data,10 were used as the proxy for admission costs in these cases.

Physician Fees

Estimated physician fees for the index TAVR procedure were taken from the Medicare fee schedule and included a primary operator (current fees for surgical aortic valve replacement were used for this unknown value), plus fees for a surgical assistant, cardiac anesthesia (based on measured procedure duration), and intraoperative transesophageal echocardiography. Physician fees for initial consultation and daily care during the remainder of the initial hospital stay and for any additional cardiovascular procedures performed during the index hospitalization (eg, vascular surgery, endovascular stenting) were also taken from the Medicare fee schedule. For follow-up consultations, physician fees were estimated based on the DRG for each admission as described previously.11

Other Costs

Data on rehabilitation facility stays, nursing home stays, and outpatient resource use (emergency room visits, physician office visits, outpatient cardiac testing) were collected by the enrolling sites at each study follow-up visit. These measures of resource use were converted to costs using national average per diem rates for residential care and Medicare reimbursement rates for outpatient care based on the Medicare Fee Schedule.
Survival curves were fitted separately for the TAVR and control groups by use of exponential, Weibull, log-normal, log-logistic, logistic, and normal models. Covariates included age, sex, and medical history such as diabetes mellitus, coronary artery disease, peripheral vein disease, myocardial infarction, stroke/transient ischemic attack, prior percutaneous coronary intervention, and prior coronary artery bypass graft. To improve the model fit for the TAVR group and to optimize the resulting survival projections, we conditioned the model on survival at 3 months to reduce the influence of periprocedural events not expected to affect long-term survival. Exponential models were identified as optimal for both treatment groups based on the Akaike Information Criterion and Schwarz’s Bayesian Criterion and were used for the primary cost-effectiveness analysis. Alternative models were used as the basis for sensitivity analyses (see Statistical Analysis).

From the final survival models, patient-level survival probabilities over time were generated until the estimated survival probability was <1%. Individual survival duration was then calculated as the integral of the survival probability versus time function.

Quality-Adjusted Life Expectancy
Quality of life was assessed directly from patients at baseline, 1, 6, and 12 months with the EuroQOL (EQ-5D) health status instrument and converted to population-level utility weights with a published algorithm developed for the US population. Utility weights are measures of a person’s strength of preference for his or her state of health on the basis of a scale from 0 to 1, where 0 represents the worst possible health state (usually death) and 1 represents ideal health. Quality-adjusted life expectancy was calculated for each patient as the time-weighted average of his or her utility values, with the midpoint between assessments used as the transition between health states. Missing utility values were estimated by multiple imputation techniques, taking into account baseline patient characteristics, clinical events, number of hospitalizations, and previous utility values. Quality-adjusted life expectancy beyond the first year of follow-up was calculated as the product of projected life expectancy multiplied by the last available utility value for that individual.

Long-Term Costs
Monthly healthcare costs (including hospital costs, physician fees, outpatient services, and chronic care/rehabilitation costs) beyond the trial period were estimated on the basis of the last 6 months of observed costs for each surviving patient by multiplying these cost estimates by each patient’s projected survival duration beyond the trial.

Statistical Analysis
Categorical data are reported as frequencies, and continuous data are reported as mean±SD. Discrete variables were compared by Fisher exact test. Normally distributed continuous variables were compared by Student t test, and nonnormally distributed data were compared by the Wilcoxon rank-sum test. Cost data are reported as both mean and median values and were compared by t tests, which are appropriate given the large sample size and our focus on comparing mean costs between groups (rather than the underlying distributions). All probability values were 2-sided.

For the purposes of the cost-effectiveness analyses, future costs, life expectancy, and quality-adjusted life expectancy were discounted at 3% per year, consistent with current guidelines. Incremental cost-effectiveness ratios were calculated as the difference in mean discounted lifetime costs divided by the difference in mean discounted life expectancy or quality-adjusted life expectancy. Bootstrap resampling (5000 replications) was used to assess the joint distribution of lifetime cost and survival differences and to generate cost-effectiveness acceptability curves to explore the probability that TAVR would be economically attractive at any given cost-effectiveness threshold.

In addition to the primary analysis, we performed a number of sensitivity analyses to explore the impact of key analytic and structural assumptions on the results of our study. These analyses included plausible variations in the discount rate and the acquisition cost of the transcatheter valve; exclusion of all noncardiovascular care costs; exclusion of the costs of balloon valvuloplasty procedures; and an assessment of QALYs with the assumption of no improvement in quality of life from baseline for either group. We also considered alternative hazard functions for the model used to project survival and estimate life expectancy after TAVR. These hazard functions included Weibull, Gompertz, and an “accelerated” Gompertz function in which the shape parameter was increased to “force” survival for the TAVI group to be 1% at 10 years. We also examined results obtained by truncating our base case analysis at 5 and 10 years. Finally, to address uncertainty in our long-term cost projections, we repeated our analysis after inflating and deflating all TAVR group costs beyond 12 months by 25%.

Results
Between May 2007 and March 2009, a total of 358 patients with inoperable aortic stenosis were enrolled at 21 centers (17 US, 3 Canadian, 1 European) and randomized to either TAVR (n=179) or standard therapy (n=179). Of the 179 patients randomized to TAVR, 175 underwent a TAVR procedural attempt. Two patients died before their scheduled procedure, and in 2 other cases, the aortic annulus diameter was found to be unsuitable for TAVR by intraoperative transesophageal echocardiography, and the patients were instead treated with balloon aortic valvuloplasty.

TAVR Procedural Resource Use and Index Hospitalization Costs
Resource use and costs for the initial TAVR procedures and their associated hospital stays are summarized in Tables 1 and 2. With few exceptions, the initial procedures used a single valvuloplasty balloon and a single Edwards-Sapien valve. In 21 patients, 1 or more unplanned procedures were performed, most commonly a surgical or catheter-based peripheral arterial intervention. The mean TAVR procedural cost, excluding physician fees, was $42 806 (median $38 706), and the mean cost for the initial TAVR admission, including physician fees, was $78 542 (median $67 551). Mean length of stay was 10.1 days, of which 8.6 days were after the procedure.

Follow-Up Resource Use and Costs
Follow-up resource use and costs for the 2 treatment groups are summarized in Table 3. Of the first 12 months of follow-up,
Mean baseline EQ-5D utility scores were 0.59 in the TAVR group and 0.57 in the control group. Among surviving patients in the control group, EQ-5D scores also increased to 0.64 at 30 days, 0.66 at 6 and 12 months in the TAVR group and 0.57 in the control group. These increased to 0.71 at 30 days and 0.72 at 6 and 12 months in the TAVR group and 0.57 in the control group. Among surviving patients in the control group, EQ-5D scores also increased to 0.64 at 30 days, 0.66 at 6 months, and 0.62 at 1 year. The between-group differences in utility weights were statistically significant ($P<0.05$) at each follow-up time point.

### Projections Beyond 12 Months

As reported previously, 12-month survival was 70% for the TAVR group versus 50% for the control group, an absolute survival advantage of 20% that was preserved through 2.5 years of follow-up. Observed survival duration through a maximum of 30 months was 1.25 years with TAVR (95% CI, 1.15–1.36) and 0.88 years (95% CI, 0.78–0.97) with standard therapy, a difference of 0.36 years (95% CI 0.23–0.50). An exponential hazard function best approximated observed survival data for each treatment group based on model goodness-of-fit statistics. Projected survival based on several different hazard functions is displayed along with observed survival in Figure 1.

On the basis of the exponential survival models, total life expectancy for the TAVR group was estimated to be 3.1 years compared with 1.2 years for the control group, a difference of 1.9 years (95% CI, 1.5–2.3 years). This difference decreased to 1.6 years (95% CI, 1.3–1.9 years) after the 3% discount rate was applied. On the basis of these life expectancy projections and the empirical cost data from the last 6 months of follow-up (TAVR $22 429/year; control $35 343/year), lifetime medical care costs beyond the trial were estimated at $43 664 per patient for the TAVR group and $16 282 per patient for the control group.

### Cost-Effectiveness Analysis

On the basis of the empirical data for the first 12 months of follow-up and our trial-based survival and cost projections, we estimated a difference in discounted lifetime medical care costs of $79 837 per patient (95% CI, $67 463–$92 349) and a gain in discounted life expectancy of 1.6 years, which resulted in a lifetime incremental cost-effectiveness ratio (ICER) of $50 212 per life-year gained (95% CI, $41 392–$62 591 per life-year gained). Bootstrap simulation demonstrated that the ICER was fairly stable, with 95% of replicates <$60 000 per life-year gained and 100% <$100 000 per life-year gained (Figures 2 and 3).

### Sensitivity Analyses

Table 4 summarizes the results of key secondary and sensitivity analyses. Although utility scores were higher at each follow-up

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**Table 2. Resource Use and Costs for TAVR Hospitals (n=175)**

<table>
<thead>
<tr>
<th></th>
<th>Mean±SD (Median)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length of stay, d</strong></td>
<td></td>
</tr>
<tr>
<td>ICU</td>
<td>4.0±7.0 (2)</td>
</tr>
<tr>
<td>Non-ICU</td>
<td>6.1±5.4 (6)</td>
</tr>
<tr>
<td>Postprocedure</td>
<td>8.6±9.8 (6)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>10.1±10.1 (7)</td>
</tr>
<tr>
<td><strong>Costs, $</strong></td>
<td></td>
</tr>
<tr>
<td>TAVR procedure</td>
<td>42 806±15 206 (38 706)</td>
</tr>
<tr>
<td>Room and ancillary costs</td>
<td>30 757±27 484 (22 150)</td>
</tr>
<tr>
<td>Physician fees</td>
<td>4979±1697 (4521)</td>
</tr>
<tr>
<td><strong>Total for initial hospitalization</strong></td>
<td>78 542±33 799 (67 551)</td>
</tr>
</tbody>
</table>

TAVR indicates transcatheter aortic valve replacement; ICU, intensive care unit.

**Table 3. Cumulative 1-Year Resource Use and Costs**

<table>
<thead>
<tr>
<th></th>
<th>TAVR Group (n=179)</th>
<th>Control Group (n=179)</th>
<th>Difference (TAVR–Control) (95% CI)</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Follow-up hospitalizations</td>
<td>1.0±1.3</td>
<td>2.2±1.5</td>
<td>−1.1 (−0.8, −1.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Cardiovascular</td>
<td>0.5±0.8</td>
<td>1.7±1.2</td>
<td>−1.2 (−1.0, −1.4)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Noncardiovascular</td>
<td>0.5±0.8</td>
<td>0.5±0.8</td>
<td>0.1 (−0.1, 0.2)</td>
<td>0.43</td>
</tr>
<tr>
<td>Rehabilitation days</td>
<td>4.6±21.3</td>
<td>3.8±18.7</td>
<td>0.7 (−3.5, 4.9)</td>
<td>0.75</td>
</tr>
<tr>
<td>SNF days</td>
<td>14.4±56.5</td>
<td>7.9±39.5</td>
<td>6.5 (−3.6, 16.7)</td>
<td>0.21</td>
</tr>
<tr>
<td>Follow-up hospitalization costs, $</td>
<td>18 074±35 320</td>
<td>45 093±46 943</td>
<td>−27 018 (−35 654, −18 383)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Rehabilitation costs, $</td>
<td>4674±21 825</td>
<td>3951±19 209</td>
<td>723 (−3551, 4997)</td>
<td>0.74</td>
</tr>
<tr>
<td>SNF costs, $</td>
<td>4142±16 225</td>
<td>2270±11 344</td>
<td>1 872 (−1038, 4782)</td>
<td>0.21</td>
</tr>
<tr>
<td>Other outpatient costs, $</td>
<td>2400±2584</td>
<td>2308±2715</td>
<td>91 (−460, 642)</td>
<td>0.74</td>
</tr>
<tr>
<td>Total follow-up costs, $</td>
<td>29 289±48 542</td>
<td>53 621±53 301</td>
<td>−24 331 (−34 929, −13 735)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Total 12-mo costs, $</td>
<td>106 076±60 206</td>
<td>53 621±53 301</td>
<td>52 455 (40 635, 64 275)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

All data are presented as mean±SD.

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time point in the TAVR group, mean utility scores in this population remained lower than normal, even after successful TAVR. As a result, the gain in quality-adjusted survival was smaller than the gain in absolute survival, and the cost-utility analysis yielded an ICER of $61,889 per QALY gained (95% CI, $49,551–$78,361 per QALY gained).

These results were relatively insensitive to changes in the discount rate or the assumed acquisition cost of the study device or to the exclusion of costs associated with balloon valvuloplasty procedures from the control group. If the analysis were restricted to only costs related to cardiovascular care, then the lifetime incremental costs of TAVR decreased to $53,000 per patient, with a resulting ICER of $33,860 per life-year and $41,700 per QALY gained. If effectiveness were measured in QALYs, but we assumed no improvement over time in the baseline utility scores for either group, then the ICER for TAVR became less favorable at $83,000 per QALY gained.

Finally, our results were only modestly sensitive to alternative time horizons, alternative hazard functions for TAVR group life expectancy projections, or variations in our estimates of annual costs beyond the first year of follow-up (Figure 1; Table 4). Only an accelerated Gompertz hazard function that yielded 10-year survival of 1% in the TAVR group resulted in an ICER $60,000 per life-year gained, and 99% of bootstrap simulations yielded ICER results <$100,000 per life-year gained in every scenario examined.

**Discussion**

In this trial-based analysis, we found that TAVR, performed in a population of patients unsuitable for surgical aortic valve replacement, was associated with procedural costs of $43,000.
and initial hospitalization costs of $78 000. Although follow-up costs through 12 months were significantly lower with TAVR, cumulative 1-year costs remained $55 000 higher per patient with TAVR than with standard, nonsurgical therapy, a difference that increased to $79 000 per patient when costs associated with added years of life were also considered. Over the observed follow-up period, TAVR was associated with a survival benefit of 0.5 years, which increased to 1.9 years (1.6 years after discounting) when the empirical survival data were projected over a lifetime horizon. On the basis of these data, the threshold used for reimbursement policy in the United States,19 the ICER for TAVR compared with standard care was estimated at $50 200 per year of life gained or $62 000 per QALY gained, results that remained relatively stable across a broad range of uncertainty and sensitivity analyses.

At the present time, there is no explicit cost-effectiveness threshold used for reimbursement policy in the United States,19 although formal economic assessments are often required in the evaluation of new health technologies in other national health systems.20 Outpatient hemodialysis has long been referenced as a benchmark for the cost-effectiveness of new medical interventions in the United States, because it has been mandated as a covered benefit under the Medicare program. Recent studies have estimated the cost-effectiveness of hemodialysis for end-stage renal disease at $70 000 per life-year gained.21 The ICER for TAVR versus standard care of $50 000 per year of life gained from the present study is thus favorable compared with the dialysis benchmark. The cost-effectiveness of TAVR for patients with inoperable aortic stenosis is also well within the range of other cardiovascular technologies commonly used in the United States,22 including implantable defibrillators for the primary prevention of sudden cardiac death23,24 and catheter ablation for atrial fibrillation,25 and far below recent estimates of the cost-effectiveness of percutaneous coronary intervention versus medical therapy for patients with stable coronary artery disease26 or left ventricular assist devices for destination therapy.27

In addition to the main results, the present study provides several important insights into the cost-effectiveness of life-extending therapy among the very elderly. First, we found that despite providing substantial cost offsets during the first year of follow-up, among the highly complex, inoperable patients enrolled in this trial, TAVR did not result in long-term cost savings. In fact, our empirically derived projections suggest that the cost difference between TAVR and standard therapy actually increased beyond the first year of follow-up as a result of the greater life-expectancy for the TAVR group coupled with the high cost of ongoing medical care even after successful valve replacement in this uniquely challenging patient population.

The results of the present study were slightly less favorable when expressed as costs per QALY gained rather than costs per life-year gained, even though symptoms, quality of life, and functional status improved more with TAVR than in the control group.6,28 This is because the years of life added for the TAVR group were added at less than perfect quality, a finding that would be expected given the patient population under study. If quality of life had not improved with TAVR, as we explored in sensitivity analysis, the ICER would have been substantially higher. Although a 1996 expert panel recommended the use of QALYs as the standard effectiveness measure in health economic analysis,17 this guidance is not universally accepted both because of imprecision in the methods used to estimate QALYs and because there is both philosophical and political opposition to the notion that

### Table 4. Lifetime Cost-Effectiveness and Selected Sensitivity Analyses

<table>
<thead>
<tr>
<th>Scenario Description</th>
<th>Lifetime Costs, $</th>
<th>Life-Years or QALYs*</th>
<th>ICER, $/LYG</th>
<th>Probability ≤$50 000 per LYG, %</th>
<th>Probability ≤$100 000 per QALY, %</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Base case</strong></td>
<td>149 740</td>
<td>69 903</td>
<td>79 837</td>
<td>2.78 1.20 1.59</td>
<td>50 212</td>
</tr>
<tr>
<td><strong>QALYs</strong></td>
<td>149 740</td>
<td>69 903</td>
<td>79 837</td>
<td>2.03 0.73 1.29</td>
<td>61 889†</td>
</tr>
<tr>
<td><strong>Discount rate 0%</strong></td>
<td>156 920</td>
<td>70 915</td>
<td>86 005</td>
<td>3.11 1.23 1.88</td>
<td>45 747</td>
</tr>
<tr>
<td><strong>Discount rate 5%</strong></td>
<td>146 031</td>
<td>69 295</td>
<td>76 736</td>
<td>2.61 1.18 1.44</td>
<td>53 290</td>
</tr>
<tr>
<td><strong>Exclude noncardiovascular costs</strong></td>
<td>105 202</td>
<td>65 184</td>
<td>69 903</td>
<td>2.78 1.20 1.59</td>
<td>33 860</td>
</tr>
<tr>
<td><strong>Valve price= $20 000</strong></td>
<td>139 293</td>
<td>65 184</td>
<td>69 390</td>
<td>2.78 1.20 1.59</td>
<td>43 642</td>
</tr>
<tr>
<td><strong>Valve price= $40 000</strong></td>
<td>160 187</td>
<td>69 903</td>
<td>90 284</td>
<td>2.78 1.20 1.59</td>
<td>56 782</td>
</tr>
<tr>
<td><strong>Exclude BAV procedure costs</strong></td>
<td>149 740</td>
<td>67 118</td>
<td>82 623</td>
<td>2.78 1.20 1.59</td>
<td>51 964</td>
</tr>
<tr>
<td><strong>QALYs assuming no QOL improvement from baseline</strong></td>
<td>149 740</td>
<td>69 903</td>
<td>79 837</td>
<td>1.70 0.74 0.96</td>
<td>83 163†</td>
</tr>
<tr>
<td><strong>Gompertz model (life-years)</strong></td>
<td>143 333</td>
<td>69 903</td>
<td>73 430</td>
<td>2.50 1.20 1.30</td>
<td>56 574</td>
</tr>
<tr>
<td><strong>Accelerated Gompertz model (life-years)</strong></td>
<td>137 420</td>
<td>69 903</td>
<td>67 517</td>
<td>2.23 1.20 1.03</td>
<td>65 476</td>
</tr>
<tr>
<td><strong>Wellbull model (life-years)</strong></td>
<td>157 726</td>
<td>69 541</td>
<td>88 185</td>
<td>3.14 1.19 1.96</td>
<td>45 054</td>
</tr>
<tr>
<td><strong>Base case, 10–y time horizon</strong></td>
<td>148 180</td>
<td>69 899</td>
<td>78 281</td>
<td>2.71 1.20 1.52</td>
<td>51 670</td>
</tr>
<tr>
<td><strong>Base case, 5–y time horizon</strong></td>
<td>142 680</td>
<td>69 708</td>
<td>72 972</td>
<td>2.46 1.19 1.27</td>
<td>57 366</td>
</tr>
<tr>
<td><strong>&gt;1-y TAVR costs inflated 25%</strong></td>
<td>160 600</td>
<td>69 903</td>
<td>90 697</td>
<td>2.78 1.20 1.59</td>
<td>57 208</td>
</tr>
<tr>
<td><strong>&gt;1-y TAVR costs deflated 25%</strong></td>
<td>138 880</td>
<td>69 903</td>
<td>68 977</td>
<td>2.78 1.20 1.59</td>
<td>43 508</td>
</tr>
</tbody>
</table>

*TAVR indicates transcatheter aortic valve replacement; ICER, incremental cost-effectiveness ratio; LYG, life-year gained; QALY, quality-adjusted life-years; BAV, balloon aortic valvuloplasty; and QOL, quality of life.

*All costs and life-years (QALYs) are discounted at 3% per year unless otherwise indicated.

†ICER expressed as dollars per QALY gained.
life-years for one group might be valued differently than life-years for another group (eg, because of age, disability, or chronic health problems). Indeed, several recent economic studies of life-prolonging cardiovascular therapies have used life-years as the primary measure of effectiveness.\textsuperscript{23,29,30}

**Comparison With Previous Studies**

To the best of our knowledge, this is the first study to estimate the lifetime cost-effectiveness of TAVR for patients with inoperable aortic stenosis. Wu and colleagues\textsuperscript{31} used a combination of single-center observational data on survival and quality of life after aortic valve replacement and a computer simulation model based on historical data on the natural history of untreated valve disease to estimate the cost-effectiveness of surgical aortic valve replacement as a function of patient age. They found that for octogenarians, surgical aortic valve replacement resulted in a gain in quality-adjusted life expectancy of \(\approx 5\) years and an ICER of \(\approx \$20,000\) per QALY.

The results of the present study differ from those of Wu and colleagues\textsuperscript{31} in several important ways. First, the patient populations in the 2 studies were quite different and, in fact, mutually exclusive. By definition, the patient population in the previous study consisted of patients who were considered to be candidates for valve replacement surgery, whereas the PARTNER cohort B population was specifically selected to exclude such patients. It is therefore not surprising that the projected gain in life expectancy among operative candidates was substantially greater than for nonoperative candidates in the present study. In addition, the present study was based on empirical cost and survival data from a randomized clinical that included a parallel control group of comparable patients treated without valve replacement. Given the very large survival benefit observed in the PARTNER trial (cohort B), it appears unlikely that such a study will be repeated, the very large survival benefit observed in the PARTNER trial is comparable patients treated without valve replacement. Given present study was based on empirical cost and survival data from for nonoperative candidates in the present study. In addition, the feasibility of the care delivered in the PARTNER trial may have differed from typical community practice. For example, the frequent performance of balloon valvuloplasty in the control group of the present trial likely exceeds that used in recent clinical practice. However, results from a sensitivity analysis showed that removing the costs of balloon aortic valvuloplasty procedures (but not their likely benefit on quality of life) had little impact on our findings.

Our long-term projections of survival, quality-adjusted survival, and costs beyond the trial’s time frame are associated with uncertainty. In the absence of external data from a comparable patient population, we relied almost exclusively on observed data from the first 12 to 30 months of follow-up to inform our estimates of future outcomes. Nonetheless, the fact that nearly 50% of all enrolled patients had died by the completion of follow-up renders our estimates of life expectancy quite plausible. Indeed, a recent study\textsuperscript{32} of 5-year outcomes among Medicare patients with medically managed aortic stenosis reported a life expectancy of 1.4 years among high-risk patients and annual costs of \(\approx \$30,000\), results very similar to ours. Our projected life expectancy of 3.1 years for the TAVR group is less certain but probably not an overestimate given that the average life expectancy of an 83-year-old in the United States is roughly 7 years.\textsuperscript{33}

In conclusion, for patients with severe, symptomatic aortic stenosis who are not considered candidates for surgical valve replacement, the PARTNER trial demonstrates that TAVR significantly increases life expectancy at an incremental cost per life-year or QALY gained well within accepted values for commonly used cardiovascular technologies. Further studies will be necessary to evaluate the cost-effectiveness of TAVR for other, lower-risk patient populations and compared with other treatment strategies (eg, surgical aortic valve replacement).

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**Disclosures**

Dr Reynolds reports receiving research support from Edwards Lifesciences, Biosense Webster, and Sanofi-aventis and consulting income from Biosense Webster, Sanofi-aventis, St. Jude Medical, and Medtronic. Dr Magnuson reports receiving grant support from Eli Lilly, Daiichi Sankyo, Sanofi-aventis, and Bristol-Myers Squibb. Dr Kodali reports receiving consulting income from Edwards Lifesciences (clinical proctor). Dr O’Neill reports receiving consulting fees from Medtronic. Dr Davidson reports receiving research support from Edwards Lifesciences and Abbott Vascular and serving on the advisory board of Abbott Vascular. Dr Smith reports receiving research support from Edwards Lifesciences. Dr Leon reports receiving research support from Edwards Lifesciences and consulting income from Medtronic, and he holds stock options in Sadra Medical. Dr Cohen reports receiving research support from Edwards Lifesciences, Medtronic, Boston Scientific, Abbott Vascular, MedRad, Merck/Schering-Plough, and Eli Lilly-Daiichi Sankyo; consulting income from Schering-Plough, Eli Lilly, Medtronic, and Cordis; and speaking honoraria from Eli Lilly, The Medicines Company, and St. Jude Medical. The other authors report no conflicts.

**References**

In patients deemed ineligible for cardiac surgery, the Placement of Aortic Transcatheter Valves (PARTNER) trial recently demonstrated a 20% absolute survival difference at 12 months when transcatheter aortic valve replacement (TAVR) was compared with standard nonsurgical therapy. The costs and cost effectiveness of this clinical strategy, which would typically be applied to elderly patients, have not been evaluated previously. Empirical data regarding survival, quality of life, medical resource use, and hospital costs were collected during the PARTNER trial and used to project life expectancy, typically be applied to elderly patients, have not been evaluated previously. Empirical data regarding survival, quality of life, medical resource use, and hospital costs were collected during the PARTNER trial and used to project life expectancy, medical resource use, and hospital costs were collected during the PARTNER trial and used to project life expectancy, and lifetime medical care costs. Average costs for the initial TAVR procedure and hospital stay were $42,806 and $78,542, respectively, but follow-up costs through 12 months were approximately $24,000 lower per patient with TAVR because of higher rates of cardiovascular hospitalization with standard therapy. We projected that over a patient’s lifetime, TAVR would increase life expectancy by 1.9 years (1.6 years after application of a standard 3% discount rate to future costs and benefits) at a discounted lifetime incremental cost of $79,837. The incremental cost-effectiveness ratio for TAVR was thus estimated at $50,200 per year of life gained, or $61,889 per quality-adjusted life-year gained, values generally considered acceptable within the context of the US healthcare system. These estimates were only slightly altered when assumptions about future costs and survival were varied within plausible ranges.

**CLINICAL PERSPECTIVE**

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Cost-Effectiveness of Transcatheter Aortic Valve Replacement Compared With Standard Care Among Inoperable Patients With Severe Aortic Stenosis: Results From the Placement of Aortic Transcatheter Valves (PARTNER) Trial (Cohort B)

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In the article by Reynolds et al, “Cost-Effectiveness of Transcatheter Aortic Valve Replacement Compared With Standard Care Among Inoperable Patients With Severe Aortic Stenosis: Results From the Placement of Aortic Transcatheter Valves (PARTNER) Trial (Cohort B),” which appeared in the March 6, 2012 issue of the journal (*Circulation*. 2012;125:1102–1109), Dr William W. O’Neill failed to disclose a professional relationship with Edwards Lifesciences, Inc.

The current online version of the article has been corrected. The authors apologize for the omission.