Aortic Valve Replacement in the Elderly
Determinants of Late Outcome

Elena A. Ashikhmina, MD; Hartzell V. Schaff, MD; Joseph A. Dearani, MD; Thoralf M. Sundt III, MD; Rakesh M. Suri, MD; Soon J. Park, MD; Harold M. Burkhart, MD; Zhuo Li, MS; Richard C. Daly, MD

**Background**—Few data exist on long-term outcomes of elderly patients after aortic valve replacement. We evaluated latest follow-up information for patients ≥70 years of age after aortic valve replacement.

**Methods and Results**—Late overall survival of 2890 consecutive patients ≥70 years of age who underwent aortic valve replacement between January 1993 and December 2007 was reviewed retrospectively, analyzed, and stratified by preoperative and intraoperative variables. Observed 5-, 10-, and 15-year late postoperative survival was lower than generally expected (68%, 34%, and 8% versus 70%, 42%, and 20%, respectively; *P*<0.001). Independent predictors of late death included older age, renal failure, diabetes mellitus, stroke, myocardial infarction, immunosuppression, prior coronary artery bypass grafting, implanted pacemaker, lower ejection fraction, hypertension, and New York Heart Association class III or IV. After stratification by age–comorbidity risk score, 10-year survival for the lowest-risk group (n=946 [33%]) was similar to expected survival (55% versus 55%; *P*=0.50), but for the highest-risk group (n=564 [20%]), survival was significantly lower than expected (9% versus 26%; *P*<0.001). For 229 pairs of propensity-matched patients with mechanical or biological prostheses, survival was not significantly different (67%, 40%, and 19% versus 71%, 45%, and 7% at 5, 10, and 15 years, respectively; *P*=0.81). Structural deterioration of bioprostheses occurred in 64 patients (2.4%).

**Conclusions**—Survival of elderly patients after aortic valve replacement is influenced by age and preoperative comorbidities; 33% at lowest risk had overall survival similar to that of an age- and sex-matched general population. There was no sufficient evidence that valve type affected survival. Structural deterioration of aortic bioprostheses was rare. (*Circulation. 2011;124:1070-1078.*)

**Key Words:** aorta • risk factors • survival • valves

Degeneration of the native aortic valve (AV) is a common disease in the aging population, and AV replacement (AVR) is performed frequently in elderly patients. Most clinicians favor the use of bioprostheses for valve substitutes, mainly because of the anticipated limited life expectancy of elderly patients and to avoid anticoagulation. The aortic bioprosthesis is the preferred device for patients >70 years of age, according to 2006 American College of Cardiology/American Heart Association (ACC/AHA) guidelines. Recent publications, however, have shown that older patients who receive mechanical prostheses have equivalent quality of life and excellent survival compared with patients who receive tissue valves. In the present study, we evaluated outcomes of elderly patients (≥70 years of age) after AVR and focused our analysis on the identification of patients with increased longevity and the potential impact of valve type on overall survival.

**Clinical Perspective on p 1078**

**Methods**

This retrospective study of prospectively gathered data was approved by the Mayo Clinic Institutional Review Board. Between January 1993 and December 2007, a total of 5594 patients underwent AVR at our institution; 3205 (57%) of them were ≥70 years of age. Of these older patients, 2890 (90%) met enrollment criteria for the study: (1) AVR with mechanical or biological prosthesis, (2) no prior intervention on the AV, (3) no concomitant aortic root reconstruction, (4) no aortic homograft, and (5) informed consent to participate in research. Patients who had a concomitant coronary artery bypass graft (CABG) were included, as were patients who had CABG before AVR.

We reviewed medical records to abstract demographic characteristics, comorbid conditions, details of operations, and results of...
echocardiographic examinations. Late follow-up was obtained from medical records (when available), from written correspondence or telephone conversations with patients or patients’ physicians, or from questionnaires mailed directly to patients. When death data were missing from the medical record, the vital records office in the Minnesota Department of Health was contacted to obtain death certificates, and the information was abstracted from those state records.

We used the Olmsted County, Minnesota, general population database for comparative survival analysis. We used univariate and multivariable Cox regression models to identify factors associated with overall mortality (Table I in the online-only Data Supplement).

Additionally, to classify conditions that might alter the risk of mortality, we developed an age–comorbidity risk-scoring system for survival based on the results of the risk factors analysis. We empirically categorized patients by their risk scores as category 1 (score, 1 to 5), 2 (score, 6 to 8), 3 (score, 9 to 11), or 4 (score, ≥12). We then repeated the survival analysis for each category and compared survival with that expected in the general population.

We opted to evaluate the influence of choice of AV prosthesis on late survival. To minimize potential bias related to preoperative selection of the prosthetic valve, we generated a propensity score based on relevant baseline characteristics (Table I in the online-only Data Supplement) and analyzed late survival of propensity score–matched pairs of patients with mechanical and biological prostheses. We then compared the survival of patients with mechanical and biological valves according to risk groups. Furthermore, we compared rates of reoperation in patients with mechanical and biological prostheses.

For those patients with bioprostheses who did not have reoperation on the AV and who had follow-up at least 90 days after surgery, we analyzed anticoagulation status at latest follow-up and late valve performance by echocardiography. The artificial cutoff of 90 days was chosen to exclude cases of conventional anticoagulation for 3 months after AVR with a bioprosthesis.

The grade of aortic stenosis and regurgitation were defined as outlined in the ACC/AHA 2006 Guidelines for the Management of Patients With Valvular Heart Disease.6

All transthoracic echocardiographic examinations were performed according to the guidelines of the American Society of Echocardiography. We used visual qualitative assessment of left ventricular ejection fraction, with concomitant quantitative evaluation of left ventricular dimensions.8 For clinical evaluation of native AVs or bioprostheses, we accessed aortic jet velocity (m/s) using continuous-wave Doppler from multiple acoustic windows to determine the highest velocity. We then calculated mean transaortic gradient (mm Hg), a pressure gradient derived from jet velocity, using the Bernoulli equation ($P = 4V^2$). We also evaluated AV area (cm$^2$) by the continuity equation: $AV = \frac{CSA_{LVED} \times TVILVOT \times TVILVA}{CSA_{LVOT}}$, where CSA$_{LVED}$ is the cross-sectional area of the left ventricular outflow tract, TVILVOT is the time velocity integral of the left ventricular outflow tract, and TVILVA is the time velocity integral of the AV. The left ventricular outflow tract and AV velocities were measured with pulsed-wave Doppler.9

We used Enterprise Data Trust, a proprietary institutional repository system containing patient care data, to extract warfarin prescription data and to identify patients who were prescribed warfarin beyond 3 months after AVR.

Statistical Analysis

Descriptive statistics for categorical variables are reported as frequency and percentage; continuous variables are reported as mean±SD or median (range), as appropriate. Categorical variables were compared between valve types with the χ2 test. Continuous variables were compared with the 2-sample t test or the Wilcoxon rank sum test as appropriate. The Kaplan-Meier method was used to draw survival curves and to calculate 5-, 10-, and 15-year survival statistics and freedom from reoperation on the AV.

Univariate and multivariable Cox regression models were used to identify factors associated with overall mortality. The multivariable model considered univariately significant variables (P<0.05), with model selection using the stepwise method; backward and forward methods resulted in the same model. The scaled Schoenfeld residuals stratified by valve types were plotted against time to test the proportional hazard assumption, and from the plot, the residual for the 2 groups stayed parallel and steady around 0, except at the very end of follow-up. Considering the robustness of the Cox regression procedure, we assumed that the Cox regression model was appropriate for use in the present study.

The age–comorbidity risk scoring system for survival was developed on the basis of the multivariable Cox regression model. The risk factor with the smallest model coefficient was assigned a score of 1, and the other model coefficients were divided by this coefficient and rounded to the nearest integer, which was their corresponding score.

To ensure that the valve types were compared fairly, regardless of the difference between the patient populations, we calculated a propensity score for each patient on the basis of that patient’s characteristics, including comorbidities. Patients with mechanical or tissue valves were then matched on the basis of their propensity scores. Finally, the survival outcomes were compared between the propensity score–matched mechanical and tissue valve groups.

All the tests were 2 sided. A value of $P<0.05$ was considered statistically significant. Statistical analysis was conducted with the use of SAS 9.13 software (SAS Institute, Inc, Cary, NC).

The authors had full access to and take full responsibility for the integrity of the data. All authors have read and agree to the manuscript as written.

Results

The study group consisted of 2890 patients; 2658 patients (92%) had biological prostheses and 232 patients (8%) had mechanical prostheses. The most commonly used biological valve was the Carpentier-Edwards pericardial bioprosthesis (Edwards Lifesciences, Irvine, CA; n=1712 [64%]), followed by the Medtronic Mosaic porcine bioprosthesis (Medtronic, Inc, Minneapolis, MN; n=357 [13%]). The most commonly used mechanical valve was the St. Jude Medical mechanical heart valve (St. Jude Medical, Inc, St Paul, MN; n=181 [78%]).

The age distribution of the 2890 study patients was as follows: 884 patients (31%) were 70 to 74 years of age; 935 (32%) were 75 to 79 years of age; 724 (25%) were 80 to 84 years of age; and 347 (12%) were ≥85 years of age. More than one third of all patients were ≥80 years of age. Baseline characteristics of study patients are listed in Table I. Patients receiving biological valves were generally similar to those receiving mechanical valves, except in the areas of age (patients with bioprostheses were older), status of the operation (the more urgent cases were in the group with bioprostheses), and frequency of prior operations (with cardiopulmonary bypass, particularly CABG, being higher in patients with mechanical valves). Overall, 12% of patients had prior cardiac surgery with cardiopulmonary bypass, and concomitant CABG was performed in slightly more than one half of the study group (Table 1).

Among 2890 study patients, 2757 patients (95%) had aortic stenosis, and 2309 patients (80%) had some degree of aortic insufficiency, which was mild in 519 patients (18%), moderate in 1196 (41%), and severe in 594 (21%). Only 133 patients (5%) had isolated aortic regurgitation without stenosis. Twenty-seven patients (1%) had a history of infectious endocarditis of the AV. Indications for AVR were severe symptomatic aortic stenosis, moderate to
Table 1. Baseline Characteristics of Elderly Patients Undergoing Aortic Valve Replacement

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>All Patients (n=2890)</th>
<th>Biological Valve (n=2658)</th>
<th>Mechanical Valve (n=232)</th>
<th>P*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, mean±SD, y</td>
<td>78±5</td>
<td>78±5</td>
<td>74±3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Male sex, n (%)</td>
<td>1814 (63)</td>
<td>1659 (62)</td>
<td>155 (67)</td>
<td>0.15</td>
</tr>
<tr>
<td>BSA, mean±SD, m²</td>
<td>1.9±0.2</td>
<td>1.9±0.2</td>
<td>2.0±0.2</td>
<td>0.03</td>
</tr>
<tr>
<td>NYHA class, n (%)</td>
<td></td>
<td></td>
<td></td>
<td>0.60</td>
</tr>
<tr>
<td>II</td>
<td>767 (27)</td>
<td>709 (27)</td>
<td>58 (25)</td>
<td></td>
</tr>
<tr>
<td>III or IV</td>
<td>2123 (73)</td>
<td>1947 (73)</td>
<td>173 (75)</td>
<td></td>
</tr>
<tr>
<td>Procedure status, n (%)</td>
<td></td>
<td></td>
<td></td>
<td>0.003</td>
</tr>
<tr>
<td>Elective</td>
<td>2615 (90)</td>
<td>2392 (90)</td>
<td>223 (96)</td>
<td></td>
</tr>
<tr>
<td>Urgent</td>
<td>258 (9)</td>
<td>250 (9)</td>
<td>8 (3)</td>
<td></td>
</tr>
<tr>
<td>Emergent</td>
<td>17 (1)</td>
<td>14 (1)</td>
<td>3 (1)</td>
<td></td>
</tr>
<tr>
<td>CPB time, mean±SD, min</td>
<td>94±41</td>
<td>94±41</td>
<td>93±42</td>
<td>0.67</td>
</tr>
<tr>
<td>Cross-clamping time, mean±SD, min</td>
<td>64±26</td>
<td>64±26</td>
<td>63±26</td>
<td>0.62</td>
</tr>
<tr>
<td>CABG, n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Concomitant</td>
<td>1507 (52)</td>
<td>1396 (53)</td>
<td>111 (48)</td>
<td>0.13</td>
</tr>
<tr>
<td>Prior</td>
<td>350 (12)</td>
<td>310 (12)</td>
<td>40 (17)</td>
<td>0.01</td>
</tr>
<tr>
<td>Previous operations with CPB, n (%)</td>
<td>359 (12)</td>
<td>320 (12)</td>
<td>39 (17)</td>
<td>0.04</td>
</tr>
<tr>
<td>LVEF, mean±SD, %</td>
<td>57±15</td>
<td>57±15</td>
<td>56±16</td>
<td>0.78</td>
</tr>
<tr>
<td>Total time in ICU, mean±SD (median [range]), h</td>
<td>68±126 (37 [0–2346])</td>
<td>68±128 (40 [0–2346])</td>
<td>51±36 (37 [19–142])</td>
<td>0.66</td>
</tr>
<tr>
<td>Mechanical ventilation, mean±SD (median [range]), h</td>
<td>28±92 (14 [0–1709])</td>
<td>28±94 (13 [0–1709])</td>
<td>20±23 (14 [0–117])</td>
<td>0.46</td>
</tr>
<tr>
<td>Postoperative complications, n (%)†</td>
<td>1874 (65)</td>
<td>1728 (65)</td>
<td>146 (63)</td>
<td>0.30</td>
</tr>
<tr>
<td>New-onset atrial fibrillation</td>
<td>1204 (42)</td>
<td>1118 (42)</td>
<td>86 (37)</td>
<td>0.30</td>
</tr>
<tr>
<td>Prolonged mechanical ventilation</td>
<td>404 (14)</td>
<td>366 (14)</td>
<td>38 (16)</td>
<td>0.27</td>
</tr>
<tr>
<td>Reoperation for bleeding</td>
<td>159 (6)</td>
<td>141 (5)</td>
<td>18 (8)</td>
<td>0.12</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>81 (3)</td>
<td>75 (3)</td>
<td>6 (3)</td>
<td>0.90</td>
</tr>
<tr>
<td>IABP, n (%)</td>
<td>138 (5)</td>
<td>122 (5)</td>
<td>16 (7)</td>
<td>0.12</td>
</tr>
<tr>
<td>In-hospital mortality, n (%)</td>
<td>120 (4)</td>
<td>108 (4)</td>
<td>12 (5)</td>
<td>0.44</td>
</tr>
<tr>
<td>Length of hospitalization, mean±SD (median [range]), d</td>
<td>9.7±8.7 (8 [0–141])</td>
<td>9.7±8.5 (8 [0–141])</td>
<td>10.5±10.4 (8 [0–133])</td>
<td>0.03</td>
</tr>
<tr>
<td>Available follow-up, mean±SD (median [range]), y</td>
<td>5.1±3.6 (4.7 [0–16.3])</td>
<td>5.0±3.5 (4.6 [0–16.1])</td>
<td>6.5±4.2 (6.4 [0–16.3])</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

BSA indicates body surface area; NYHA, New York Heart Association; CPB, cardiopulmonary bypass; CABG, coronary artery bypass graft; LVEF, left ventricular ejection fraction; ICU, intensive care unit; and IABP, intra-aortic balloon pump.

*P value for comparison between valve types.
†Only the most frequent postoperative complications are listed.

Factors evaluated as potential predictors of late death are listed in Table I in the online-only Data Supplement. Univariate analysis revealed that the association of all tested variables with late death was significant, with the exception of sex, body mass index, and infectious endocarditis. Evidence that the type of aortic prosthesis had a significant impact on survival was marginal (hazard ratio, 1.17; 95% CI, 0.99 to 1.30; P=0.07). In a multivariable model, risk factors for late death were older age, renal failure, diabetes mellitus, stroke, myocardial infarction, immunosuppression, prior CABG, implanted pacemaker, hypertension, lower ejection fraction, and New York Heart Association class III or IV; each risk factor was assigned a score (Table 2).

The distribution of age–comorbidity risk scores in study patients was calculated for 2878 study patients (99%); information on at least 1 risk score was missing from the database for 12 patients (2 with mechanical and 10 with biological valves), so the risk score could not be estimated for them. There were 946 patients with the lowest risk severe aortic stenosis in patients undergoing CABG, and isolated moderate to severe aortic regurgitation. A few patients (<5%) with severe aortic stenosis were asymptomatic preoperatively.

Most (2787 [96%]) of the 2890 patients survived beyond hospitalization; all of them had available survival follow-up, with a mean±SD interval of 5.1±3.6 years (median, 4.7 years; range, 0.1 to 16.3 years). Almost half of the study patients (1219 [42%]) died by the follow-up closure date (July 1, 2010). “Reoperation follow-up,” when the event of repeated operation on AV could be excluded or confirmed on the basis of the patient’s data, was available for 2369 survivors of hospitalization (85%).

As illustrated in Figure 1A, overall observed survival rates in AVR patients were lower than those of an age- and sex-matched healthy population from the same time interval. The 5-, 10-, and 15-year survival rates were 68% (95% confidence interval [CI], 66 to 70), 34% (95% CI, 32 to 37), and 8% (95% CI, 6 to 11) versus 70%, 42%, and 20%, respectively (P<0.001).
score of 1 to 5: 109 (12%) with mechanical and 837 (88%) with biological valves. Seven hundred sixty-one patients (80%) had a risk score of 6 to 8: 64 (8%) with mechanical and 697 (92%) with biological valves. There were 607 patients with a risk score of 9 to 11: 32 (5%) with mechanical and 575 (95%) with biological valves. There were 564 patients in the highest risk score group: 25 (4%) with mechanical and 539 (96%) with biological valves. As shown, patients with mechanical valves had lower risk scores overall.

The survival of patients stratified by risk score is shown in Figure 1B. For patients with the lowest risk score of 1 to 5, 10-year survival was similar to expected, 55% (95% CI, 51 to 59) versus 55% (P=0.5), but it declined with higher risk scores and was significantly lower than survival in the general population. Ten-year survival in the group with a risk score of 6 to 8 was 36% (95% CI, 32 to 41) compared with expected survival of 43% (P=0.01); in the group with a score of 9 to 11, it was 20% (95% CI, 16 to 26) compared with expected survival of 34% (P=0.002); and in the group with a score ≥12, 10-year survival was 9% (95% CI, 6 to 14) compared with expected survival of 26% (P<0.001).

Total mortality for patients with biological valves was 48% (1284 of 2658 patients) compared with 63% (145 of 232 patients) for patients with mechanical valves. As mentioned previously, according to univariate analysis, the type of AV prosthesis was not a predictor of survival. We found no statistically significant difference in overall survival for patients with mechanical versus biological valves, but there was a trend toward increased longevity in patients with mechanical valves. Five-, 10-, and 15-year survival rates were 66% (95% CI, 60 to 73), 39% (95% CI, 33 to 47), and 18% (95% CI, 12 to 30) versus 68% (95% CI, 66 to 70), 33% (95% CI, 31 to 36), and 6% (95% CI, 4 to 9), respectively (P=0.07; Figure 2A). After adjusting for potential confounders, we found no statistically significant difference in survival in the 229 propensity score–matched pairs of patients with mechanical and biological valves but once again observed the same trend toward higher late survival probability in patients with mechanical valves. Five-, 10-, and 15-year survival rates were 67% (95% CI, 61 to 73), 40% (95% CI, 33 to 47), and 19% (95% CI, 12 to 30) versus 71% (95% CI, 65 to 77), 45% (95% CI, 38 to 53), and 7% (95% CI, 3 to 17), respectively (P=0.81; Figure 2B). After excluding cases of perioperative death, we confirmed higher later survival in patients with mechanical valves compared with patients with biological valves: 70% (95% CI, 64 to 76), 41% (95% CI, 35 to 49), and 20% (95% CI, 12 to 31) versus 71% (95% CI, 69 to 73), 35% (95% CI, 32 to 37), and 6% (95% CI, 4 to 9; P=0.04) at the 5-, 10-, and 15-year follow-up, respectively. However, 15-year survival data were based on records available for only 6 patients with mechanical and 15 patients with biological valves (Figure 2A).

Because of an uneven distribution of patients with different valve types in risk score groups and an overall
higher percentage of patients with lower age–comorbidity risk scores in the mechanical valve group, we hypothesized that our 229 propensity-matched patients with biological valves might not necessarily represent the whole group with biological valves perfectly but could be relatively healthier or younger. We then compared survival of patients with different valve types stratified by risk scores. Five- and 10-year survival was similar for patients with mechanical or biological valve types in the lowest risk group: 83% (95% CI, 76 to 90) and 57% (95% CI, 48 to 68) versus 85% (95% CI, 82 to 87) and 54% (95% CI, 49 to 59), respectively ($P=0.21$; Figure 2C). There was no significant difference in 5- and 10-year survival in patients with mechanical versus biological valves who had risk scores from 6 to 8: 63% (95% CI, 52 to 76) and 32% (95% CI, 22 to 47) versus 71% (95% CI, 67 to 75) and 36% (95% CI, 31 to 42), respectively ($P=0.57$). There was also no significant difference in 5- and 10-year survival in patients with mechanical versus biological valves who had risk scores from 9 to 11: 52% (95% CI, 37 to 73) and 20% (95% CI, 8 to 49) versus 60% (95% CI, 55 to 64) and 20% (95% CI, 16 to 26), respectively ($P=0.42$). There was, however, significantly lower survival in the highest risk group in patients with mechanical valves compared with patients with biological valves. Five- and 10-year survival was 24% (95% CI, 12 to 48) and 4% (95% CI, 1 to 27) versus 46% (95% CI, 41 to 51) and 10% (95% CI, 7 to 14), respectively ($P=0.004$; Figure 2D).

The risk of reoperation for study patients was low at 2.1% (50 of 2369 patients with available reoperation follow-up); 5 patients with mechanical valves underwent reoperation compared with 45 patients with bioprostheses. There was no statistically significant difference in freedom from reoperation between patients with mechanical and biological valves (at 5-, 10-, and 15-year follow-up, it was 98%, 96%, and 90% versus 98%, 95%, and 90%, respectively; $P=0.85$; Figure 3).

Because the number of reoperations might lead to underestimation of the rate of structural valve failure in older patients who would be considered poor candidates for reoperation owing to age or clinically significant illness, we investigated the status of bioprostheses on the
basis of the latest echocardiographic examination. Among 2658 patients with bioprostheses, 1928 patients (73%) were alive, had follow-up beyond postoperative day 90, and had no reoperation on the aortic prosthesis. Late transthoracic echocardiograms were available for 1218 (63%) of these 1928 patients, and the mean interval to last echocardiographic examination was 4.4±3.2 years (maximum, 16 years; Table 3). In 16 of these 1218 patients (1%), the mean±SD transvalvular gradient was ≥40 mm Hg (46±8 mm Hg), the AV area (estimated by the continuity equation) was 1.0±0.3 cm², and the AV maximal instantaneous gradient was 82±11 mm Hg, which suggests prosthetic AV stenosis. Three additional patients (0.2%) had moderate or moderate to severe regurgitation through the aortic bioprosthesis. Overall, 19 of 1218 patients (1.6%) with bioprostheses had a high prosthetic gradient and/or at least moderate aortic regurgitation on their latest transthoracic echocardiogram.

We grouped 19 patients with bioprostheses who had echocardiographic evidence of structural valve deterioration with 45 patients with bioprostheses who underwent reoperation (64 of 2190 patients with bioprostheses [2.9%] who survived hospitalization and had reoperation follow-up). We reassessed the rate of reoperation in patients with mechanical and biological prostheses and found no statistically significant difference between the 2 groups (the 5-, 10-, and 15-year freedom from reoperation for patients with mechanical valves was 98%, 96%, and 96% versus 98%, 93%, and 85%, respectively, for patients with biological valves [P=0.27]).

At the latest follow-up, all patients with mechanical valves were receiving lifelong anticoagulation with warfarin. Of the 2658 patients with bioprostheses, 1928 patients (73%) were alive and had follow-up beyond 3 months postoperatively; 119 (6%) of these 1928 had been prescribed warfarin after postoperative day 90. Importantly, this finding may underestimate the number of patients taking anticoagulation because information on warfarin prescriptions was available only for those who were followed up and received prescriptions at our institution. However, it is unlikely that this bias is significant because most of these elderly patients visited our clinic regularly; for instance, survival follow-up was available for 100% of the study patients.

### Discussion

The decision between continued medical management and operation on the open heart in an elderly population is challenging for both patients and physicians. One reason is the generally unpredictable long-term prognosis after AVR, which depends on multiple factors related to the patient and the procedure.

This investigation summarized our 15-year experience with AVR in elderly patients (≥70 years of age), focusing on survival, predictors of late death, rates of reoperation, and influence of valve type on survival. Of note, during that time frame, more than one half of the patients who underwent AVR at our institution were ≥70 years of age.

Although some aspects of our results are similar to those reported in previous publications, this study is remarkable because of the large number of patients enrolled (n=2890), our comparison of survival in older patients and an age- and sex-matched cohort, and our use of a risk score for late survival. We also evaluated the status of bioprostheses and estimated the rate of structural valve deterioration on the basis of the latest echocardiographic examinations.

The early mortality after AVR (4% overall) in our study patients (Table 1) compares favorably with that in other reports of valve replacement in elderly cohorts (4.1% to 8.8%). However, overall survival was lower than that for an age- and sex-matched population (P<0.001). This finding can be explained by the heterogeneity of the study group participants and the presence of multiple comorbid illnesses. First, almost one half of the elderly patients who underwent AVR also had associated coronary artery disease (Table 1; percentage of concomitant to prior CABG), which is a significant risk factor for late mortality. Aortic valve replacement and concomitant CABG have been associated with poorer survival than that in patients with isolated AVR regardless of valve type. Our analysis confirms the negative impact of coronary artery disease on late survival (Table 2).

In addition, many of our study patients had numerous other risk factors and comorbid conditions (Table 2) that decrease late survival, including renal failure, diabetes mellitus, history of stroke, myocardial infarction, immu-

---

**Table 3. Echocardiographic Characteristics of 1218 Biological Valves at the Latest Follow-up**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>AV area by continuity equation TVI, cm²</td>
<td>1.79±0.67</td>
</tr>
<tr>
<td>AV mean gradient, mm Hg</td>
<td>16±8</td>
</tr>
<tr>
<td>AV maximum instantaneous gradient, mm Hg</td>
<td>29±14</td>
</tr>
<tr>
<td>Left ventricular ejection fraction, %</td>
<td>58±14</td>
</tr>
</tbody>
</table>

AV indicates aortic valve; TVI, time velocity integral. Values are mean±SD.
nosuppression, implanted pacemaker, hypertension, reduced ejection fraction, and advanced symptoms of cardiac disease (New York Heart Association class III and IV). Varadarajan et al reported that older age, lower ejection fraction, and renal failure were independent predictors of poorer survival after AVR in octogenarians. Silberman et al found that older age and renal failure, but not coronary artery disease, increased the risk of late mortality. Low ejection fraction was associated with poorer outcome in a study by Chiappini et al. These observations suggest that referral of patients to a cardiac surgeon for AVR should occur sooner rather than later. Congestive heart failure with decreased ejection fraction and other chronic comorbidities substantially decreases the chances for longer survival after AVR.

However, many elderly patients have few associated illnesses and excellent late survival. In this study, approximately one third of patients had a risk score of ≤5, and their 10-year survival was 55%, similar to what was expected (P=0.5). In contrast, survival was poorer for patients with higher risk scores (Figure 1B). This finding suggests that AVR itself plays a minimal role in late mortality, which is influenced primarily by older age and by the presence of clinically significant comorbid conditions at the time of surgery.

There is uncertainty about whether the type of prosthetic valve (mechanical or biological) had a substantial impact on survival of patients in this study (Figure 2). Previous investigations on the influence of valve type on survival are conflicting. Davis et al observed similar survival among 211 elderly patients receiving mechanical or biological AV prostheses. Milano et al reported a 10-year survival of 51% for 222 patients with mechanical valves versus 33% for 133 patients with biological AVR (P=NS). Similar findings of no difference in survival of elderly patients with mechanical or biological prostheses have been reported by others. Some investigators, however, have reported better survival in elderly patients with mechanical AVs than in those with biological valves.

A recent study from our institution found better survival after AVR with mechanical prostheses in patients 50 to 70 years of age. In addition, in the present study, after excluding cases of early mortality, we found higher late survival in patients with mechanical valves. Vicchio et al suggested that better survival in patients with mechanical aortic prostheses could be attributed to the initial bias for implanting this valve in healthier patients. Indeed, in the present study, patients with implanted mechanical valves had lower age–comorbidity risk scores. In contrast, Accola et al found mechanical valve replacement to be a predictor of late death. In a meta-analysis of data from 32 studies, Lund and Bland found no significant difference in mortality after AVR with mechanical or bioprosthetic valves after correction for age, New York Heart Association class, or concomitant CABG. Similarly, our results suggest that in adjustments for multiple confounders, the type of valve likely has minimal impact on the survival of elderly patients. However, we also observed lower survival in patients with mechanical valves who had the highest risk scores.

The potential disadvantage of bioprostheses is structural valve deterioration, but the risk of this complication is low in elderly patients. Only 45 of our 2190 patients (2%) with bioprostheses who survived beyond hospitalization and had reoperation follow-up underwent later reoperation. Davis et al reported a reoperation rate of 1.9% in a smaller group with shorter follow-up. In a recent report, McClure et al reported a 2.6% failure rate of aortic bioprostheses in a long-term study of patients with a mean age of 74.1 years; in that study, the mean follow-up was 6 years compared with 5 years for our patients.

There were fewer reoperations in our patients who received mechanical prostheses, but the difference in time-related events was not statistically significant (96% versus 90% at 15 years; P=0.85). Other investigators have reported similar findings. The better durability of bioprostheses and the rarity of reoperation in elderly versus young patients may be due to mechanical factors (eg, less stress or lower mean heart rate) and/or metabolic factors such as blunted immune response.

As Lund and Bland pointed out, however, the rates of reoperation on aortic prostheses may be underestimated because elderly and debilitated patients who are poor candidates for surgery are not referred for valve replacement. To address this possibility, we examined late follow-up echocardiograms that identified 19 patients with structural valve deterioration who had not undergone reoperation. Thus, in our experience, the rate of reoperation captured 70% of instances of structural valve deterioration (64 candidates for reoperation, 45 of whom had it). Other investigators also confirm a negligible rate of prosthesis deterioration in elderly patients.

Among the elderly patients with bioprostheses in this study, 6% were prescribed long-term warfarin anticoagulation because of other health problems (eg, atrial fibrillation or orthopedic procedures), despite an initial attempt to avoid anticoagulation. This rate of warfarin use is slightly lower than that reported by other authors, and it reaffirms the choice of biological valves to avoid complications associated with long-term anticoagulation.

Study Limitations

This is a retrospective review of prospectively gathered data, and its accuracy depended on the availability of information within the medical records. Some patients were lost to follow-up beyond postoperative years 5 to 10, but there is no reason to presume that the conclusions would have changed with more complete follow-up. We analyzed overall survival, but not cardiac- or valve-specific mortality, because it was impossible to reliably determine the cause of death for many patients. The risk-scoring system applicable to patients in this investigation should not be extrapolated to other groups of patients, primarily because it has not been validated. However, it provides a general idea of which factors might determine postoperative long-term prognosis. We used propensity matching of patients with mechanical and
biological valves to minimize potential confounders when choosing the valve type. An additional approach not used in this study would be a matched survival analysis based on propensity scores. After closer examination of risk factors, we found that matched patients with mechanical valves had lower risk scores compared to all patients with biological valves, and thus, the propensity-matched patients with biological valves likely were not representative of the much larger and broader cohort of patients with biological valves in terms of age and burden of comorbidities (eg, higher risk scores). Echocardiographic follow-up data were not available for all study patients. In addition, on average for the group, echocardiographic re-evaluation was performed 4 years postoperatively, whereas bioprosthetic valve deterioration usually occurs 10 to 15 years postoperatively; thus, the rate of bioprosthetic dysfunction may be underestimated, and no conclusions on bioprosthesis performance and durability for the longer term can be made on the basis of our data.

**Conclusion**

Our findings demonstrate that the structural deterioration of aortic bioprostheses is a rare event in elderly patients and that redo AVR is rarely necessary. Furthermore, the overall survival of patients after AVR is strongly influenced by age and preoperative comorbid conditions; the choice of valve type (mechanical or biological) does not appear to have an important impact on survival of patients in this age group. Most factors influencing late mortality after AVR in this age group are not modifiable. However, the independent influence of advanced New York Heart Association class and reduced ejection fraction on late death suggests that better later results might be achieved with earlier surgical referral.

**Disclosures**

None.

**References**


**CLINICAL PERSPECTIVE**

To identify patient factors related to increased longevity and to assess the potential impact of valve type on overall survival, we analyzed late outcomes of 2890 consecutive patients aged ≥70 years who had aortic valve replacement (AVR). Our findings may help clinicians in 2 ways. First, we found that several comorbid conditions (eg, renal failure, immunosuppression, concomitant coronary artery disease, history of myocardial infarction, or stroke) were associated with reduced late survival after AVR. These factors, in general, are not modifiable. But the finding that advanced New York Heart Association class predicted poorer late survival emphasizes the importance of not delaying operation unnecessarily in elderly patients. Delaying surgical referral until symptoms progress will not only result in a higher early mortality but will also decrease the likelihood of a satisfactory long-term survival. Second, our data show no important difference in outcome of patients by type of prosthesis. Our data are reassuring in that there is no survival penalty for use of bioprostheses in elderly patients. In addition, our findings demonstrate that the structural deterioration of aortic bioprostheses is a rare event in elderly patients and that redo AVR is rarely necessary.
Aortic Valve Replacement in the Elderly: Determinants of Late Outcome
Elena A. Ashikhmina, Hartzell V. Schaff, Joseph A. Dearani, Thoralf M. Sundt III, Rakesh M. Suri, Soon J. Park, Harold M. Burkhart, Zhuo Li and Richard C. Daly

Circulation. 2011;124:1070-1078; originally published online August 8, 2011;
doi: 10.1161/CIRCULATIONAHA.110.987560

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2011 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/124/9/1070

Data Supplement (unedited) at:
http://circ.ahajournals.org/content/suppl/2011/08/24/CIRCULATIONAHA.110.987560.DC1

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/
Supplemental Material

**Supplemental Table 1.** Variables Included in the Univariate Analysis of Predictors of Late Death\(^a\)

<table>
<thead>
<tr>
<th>Type of Variable</th>
<th>Specific Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characteristics of patients</td>
<td>Age [] Body mass index [] Left ventricular ejection fraction [] Sex</td>
</tr>
<tr>
<td>Comorbid conditions at time of aortic valve replacement</td>
<td>Arrhythmia [] Atrial fibrillation [] Cancer [] Chronic lung disease [] Congestive heart failure(^b) [] Coronary artery disease [] Diabetes mellitus [] Hypertension [] Immunosuppressive therapy(^c) [] Infectious endocarditis [] Myocardial infarction(^d) [] New York Heart Association class [] Pacemaker(^e) [] Peripheral vascular disease [] Prior cardiac operation [] Prior coronary artery bypass graft [] Renal failure(^f) [] Stroke(^e)</td>
</tr>
</tbody>
</table>
### Supplemental Table 1 (continued)

<table>
<thead>
<tr>
<th>Type of Variable</th>
<th>Specific Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operative factors</td>
<td>Concomitant coronary artery bypass graft</td>
</tr>
<tr>
<td></td>
<td>Type of prosthesis (mechanical or biologic)</td>
</tr>
<tr>
<td></td>
<td>Year of aortic valve replacement</td>
</tr>
<tr>
<td></td>
<td>Aortic regurgitation</td>
</tr>
</tbody>
</table>

*Similar variables were used to generate a propensity score.*

*Patients were considered to have congestive heart failure (CHF) if, within 2 weeks before aortic valve replacement, they had at least 1 of the following symptoms: paroxysmal nocturnal dyspnea, dyspnea on exertion due to heart failure, chest radiograph showing pulmonary congestion, or pedal edema treated with diuretics or digoxin. Note that stable or compensated cases of heart failure did not meet these criteria.*

*Any form of immunosuppressive therapy (eg, systemic corticosteroid therapy, cytostatics, antimetabolites, cyclosporine) within 30 days before aortic valve replacement (excluding topical applications, inhalers, and 1- or 2-time dose of systemic treatment as part of a preoperative protocol).*

*Myocardial infarction (MI) or history of MI (eg, MI documented in medical record, or electrocardiogram-document Q waves of 0.03 seconds in width and/or ≥one-third of the total QRS complex in 2 or more contiguous leads).*

*Permanent pacemaker placed any time before aortic valve replacement.*

*History of creatinine >2.0. Note, that prior renal transplant patients were not defined automatically as “renal failure” patients, unless their creatinine was 2.0 prior to aortic valve replacement.*
Patients who had a history of central neurologic deficit (ie, extremity weakness or loss of motion, loss of consciousness, or loss of speech) persisting for more than 72 hours were considered to have had a stroke.