Optimal selection of patients for elective abdominal aortic aneurysm repair based on life expectancy

Randall R. De Martino, MD, MS, a Philip P. Goodney, MD, MS, a Brian W. Nolan, MD, MS, a William P. Robinson, MD, b Alik Farber, MD, c Virendra I. Patel, MD, d David H. Stone, MD, d and Jack L. Cronewett, MD, f for the Vascular Study Group of New England, Lebanon, NH, and Worcester and Boston, Mass

Objective: Elective abdominal aortic aneurysm (AAA) repair is beneficial when rupture is likely during a patient’s expected lifetime. The purpose of this study was to identify predictors of long-term mortality after elective AAA repair for moderately sized AAAs (<6.5-cm diameter) to identify patients unlikely to benefit from surgery.

Methods: We analyzed 2367 elective infrarenal AAA (<6.5 cm) repairs across 21 centers in New England from 2003 to 2011. Our main outcome measure was 5-year life-table survival. Cox proportional hazards analysis was used to describe associations between patient characteristics and 5-year survival.

Results: During the study period, 1653 endovascular AAA repairs and 714 open AAA repairs were performed. Overall, 5-year survival rates were similar by procedure type (75% endovascular repair, 80% open repair; P = .14). Advanced age ≥75 years (hazard ratio [HR], 2.0; P < .01) and age >80 years (HR, 2.6; P < .01), coronary artery disease (HR, 1.4; P < .04), unstable angina or recent myocardial infarction (HR, 4.6; P < .01), oxygen-dependent chronic obstructive pulmonary disease (HR, 2.7; P < .01), and estimated glomerular filtration rate <30 mL/min/1.73 m^2 (HR, 2.8; P < .01) were associated with poor survival. Aspirin (HR, 0.8; P < .03) and statin (HR, 0.7; P < .01) use were associated with improved survival. We used these risk factors to develop risk strata for low-risk, medium-risk, and high-risk groups with survival, respectively, of 85%, 69%, and 43% at 5 years (P < .001).

Conclusions: More than 75% of patients with moderately sized AAAs who underwent elective repair in our region survived 5 years, but 4% were at high risk for 5-year mortality. Patients with multiple risk factors, especially age >80 years, unstable angina, oxygen-dependent chronic obstructive pulmonary disease, and estimated glomerular filtration rate <30 mL/min/1.73 m^2, are unlikely to achieve sufficient long-term survival to benefit from surgery, unless their AAA rupture risk is very high. (J Vasc Surg 2013;58:589-95.)

Current treatment guidelines recommend that abdominal aortic aneurysm (AAA) repair should be considered when the maximum infrarenal aortic diameter reaches 5.5 cm.1 This threshold assumes that the annual risk of rupture exceeds the operative mortality risk and that the patient will otherwise survive long enough to overcome the up-front risk of surgical treatment. Although operative mortality and AAA rupture risk have been studied extensively, less is known about long-term survival after AAA repair, particularly in high-risk patients. Screening programs may identify AAA patients at the threshold for repair,2 but patients with AAA frequently are advanced in age and present with other life-limiting comorbidities.3 Thus, some high-risk patients with 5.5-cm AAAs might die from other causes if their AAA is not repaired and not gain substantial additional life expectancy from AAA repair.4

The purpose of the present study was to identify patient risk factors associated with poor long-term survival after elective AAA repair by using data from the Vascular Study Group of New England (VSGNE) regional multicenter vascular registry. This information could then be used to optimally select patients who would most likely live long enough to benefit from elective AAA repair.

METHODS

Patients and database. This is a retrospective analysis of data collected prospectively by the VSGNE, a regional cooperative quality improvement initiative developed in 2002 to study regional outcomes in vascular surgery.5 Of note, registry data are compared with hospital claims in regular audits, and missing cases are retrieved to yield a nearly complete capture rate (>99%) to limit reporting biases.5 The Social Security Death Index was used to determine mortality status for all patients up to June 1, 2011. No patients were lost to follow-up for survival analysis. Although not all outcome events are audited, there is no benefit to under-reporting, given that reporting is anonymous.
All patients who underwent elective repair of infrarenal AAAs with diameters ≤6.5 cm by 97 participating surgeons in 21 study hospitals from 2003 to 2011 were included in the analysis. Emergency repair for rupture or urgent repairs within ≤24 hours of admission for symptoms were excluded. We only included open AAA repairs (OAR) if an infrarenal clamp location was used or endovascular AAA repairs (EVAR) that were for an infrarenal AAA, without the use of advanced techniques such as snorkels.

We excluded patients with AAA diameters >6.5 cm (by any preoperative imaging modality) because this size represents high rupture risk (>30% per year) and these patients almost always need repair. However, the rupture risk of patients with AAA diameters <6.5 cm was deemed moderate (<10% per year), so that an operating surgeon could use risk-stratification to decide whether to repair the AAA or manage it medically until the AAA expanded further.6

Prior studies have shown similar long-term survival for EVAR and OAR.7 9 Thus, we planned to combine these cohorts if our analysis determined that survival was not different between these groups in our region. We did not exclude perioperative deaths because this might have biased survival estimates for the most severe life-limiting conditions that can result in death shortly after repair. Five-year survival was determined from the VSGNE database and by matching patient information with the Social Security Death Index.

Medication use was defined as taking aspirin or statin (3-hydroxy-3-methylglutaryl-coenzyme A reductase inhibitor) preoperatively. Definitions of medical comorbidities in the VSGNE cohort have been previously published.10

Data collection and statistical analysis. Physicians, nurses, or clinical data abstractors entered data prospectively on clinical and demographic variables. Research analysts were blinded to patient, surgeon, and hospital identity. The Committee for the Protection of Human Subjects at Dartmouth Medical School approved the use of deidentifed data from VSGNE for research purposes.

Preoperative variables were compared between OAR and EVAR using χ² for categoric variables with Fisher exact correction as indicated. A two-sample t-test or Wilcoxon rank sum test was used to compare parametric or nonparametric continuous variables, respectively. For survival analysis, univariate comparisons were made with log-rank for categoric variables or Cox proportional hazards for continuous variables. Variables of clinical significance and those with a value of P < .1 by univariate survival analysis were included in a backwards stepwise multivariate Cox proportional hazards model to identify significant predictors of 5-year mortality. Schoenfeld residuals were analyzed to ensure the proportional hazards assumptions were not violated for variables associated with 5-year mortality. Variables were removed using the likelihood ratio test. Continuous variables with nonlinear risk were categorized for analysis. Age was categorized by quartiles. The β-coefficients for each significant variable were divided by a common denominator, resulting in a numeric point scale for each risk factor that could be summed to create a risk score.11 Variables were designated as major or minor risk factors by their relative number of points (1-2 points vs 3-4 points, respectively) for creation of risk strata for analysis. Values of P < .05 were considered significant.

RESULTS

Patient demographics and overall survival. During the study period, 4050 aneurysm repairs were performed; of these, 438 patients were excluded for rupture, 271 for symptomatic AAA, 401 for suprarenal clamp, and 573 for an AAA >6.5 cm. This resulted in 2367 elective repairs of infrarenal AAAs ≤6.5 cm in diameter for analysis. Of these, 1653 (70%) were by EVAR and 714 (30%) were by OAR. Patient demographics are presented in Table I. Overall, EVAR patients were slightly older than OAR patients (72.4 vs 69.3 years; P < .001) and were more likely to be men (79.4% vs 72.8%; P < .001) and have higher rates of smoking, diabetes, and congestive heart failure (Table 1). Patients undergoing EVAR were less likely to have preoperative echocardiography. However, when only those who had echocardiograms were compared, EVAR patients were more likely to have an ejection fraction <50% (24.7% vs 15.2%; P < .001).

Similarly, although EVAR patients were less likely to have preoperative stress testing, when only those with stress test results were compared, EVAR patients had higher rates of abnormal stress test results (30.8% vs 23.6%; P < .004). Although overall rates of chronic obstructive pulmonary disease (COPD) were similar between EVAR and OAR, EVAR patients had higher rates of advanced COPD (Table I). Prior AAA repair and use of aspirin, clopidogrel, and statin were similar, but β-blocker use was higher in patients undergoing OAR.

In-hospital mortality for the entire cohort was 1% (OAR, 1.8%; EVAR, 0.67%; P = .01). Survival for the entire cohort at 5 years was 77% (95% confidence interval [CI], 75%-80%). Average follow-up was 2.4 years (interquartile range [IQR], 0.9-4.6 years), with median follow-up of 1.9 years for EVAR (IQR, 0.75-4 years) compared with 3.6 years for OAR (IQR, 1.6-5.7 years) due to increased EVAR use in later years. Despite the apparent demographic differences between EVAR and OAR patients, they had similar 5-year survival (Fig 1) of 75% for EVAR (95% CI, 72%-78%) and 80% for OAR (95% CI, 76%-83%; log-rank = 0.17).

Multivariable predictors of 5-year mortality. Increasing age, particularly from age 75 to 79 (hazard ratio [HR], 2.0; 95% CI, 1.4-2.8) and age >80 years were associated with worse 5-year survival (HR, 2.6; 95% CI, 1.8-3.7; Table II), as expected. In addition, prior myocardial infarction (MI), stable angina, and recent MI or unstable angina were significantly associated with worse 5-year survival (Table II). Lastly, oxygen-dependent COPD (HR, 3.0; 95% CI, 2.0-4.5) and estimated glomerular filtration rate (eGFR) <30 mL/min/1.73 m² (HR, 3.0; 95% CI, 1.9-4.7) were associated with worse survival. Preoperative aspirin and statin use were associated...
with improved survival (Table II). Type of repair (EVAR vs OAR), aneurysm size (<5.5 vs 5.5-6.5 cm), and smoking status (former or current) did not affect survival and were not included in the final model.

Identification of risk strata for 5-year mortality. From the results of our multivariable Cox model, we identified nine independently significant predictors of 5-year mortality (Table II). The β-coefficients derived from the relative contribution of each risk factor of the Cox model were used to normalize risk factors to create a risk score (Table III, A). The relative impact on 5-year survival was greatest among those aged >80 years, recent MI or unstable angina, oxygen-dependent COPD, and eGFR <30 mL/min/1.73 m², noted by their higher point value. These risk factors were deemed major, whereas age 75-79 years, prior MI, stable angina, and lack of aspirin or statin use were considered minor. Patients in our cohort had zero (74%), one (24%), or two (2%) of these major risk factors. Because these factors had the greatest impact, patients were stratified by the number of high-risk factors or their minor risk-factor equivalent score. Specifically, low-risk patients had zero major risk factors, but could have two or fewer minor risk factors. Medium-risk patients had one major risk factor or multiple minor risk factors, whereas high-risk patients had to have two major risk factors or one major risk factor and more than two minor risk factors (Table III, B).

Using this method of categorizing patients, we identified 1403 low-risk patients (61%), 824 medium-risk patients (35%), and 83 high-risk patients (4%) within our cohort. With increasing risk strata, patients were significantly older, were more likely to be female, have larger aneurysms, to undergo EVAR, and to have higher rates of cardiac, pulmonary, and renal disease. Higher-risk patients were also less likely to be receiving statin or aspirin therapy (Table IV). These groups demonstrated significantly different survival. Survival for low-risk, medium-risk, and high-risk groups at 5 years was, respectively,
DISCUSSION

The preoperative evaluation of patients with AAA is complex. The decision to treat a patient’s aneurysm is based on a combination of the aneurysm size, morphology, and rupture risk in the context of the patient’s comorbidities and expected benefit from prophylactic repair. Patients with a high-anticipated rupture risk and favorable comorbidity profile are offered repair. However, those with a limited life expectancy from major comorbidities may not gain a survival benefit from repair if their rupture risk is low. We have identified patient factors that predict poor 5-year survival after AAA repair to assist in patient selection for intervention. It is clear from our analysis that patients with advanced age, cardiac disease, COPD, and renal disease have poor 5-year survival. These comorbidities are additive in their effect on mortality, such that those with two or more of these risk factors will experience only 50% survival at 5 years, despite repair.

Overall, our results demonstrate that the 5-year survival after AAA repair in our region is very good. EVAR and OAR patients experience a similar 5-year survival of 80% and 75% at 5 years. Of all infrarenal AAA repairs, only 4% were in patients deemed at high risk for 5-year mortality, suggesting appropriate patient selection in our region. Our survival results are similar to contemporary randomized trials (75% at 5 years)9 and are favorable compared with historical series of AAA repair with 5-year survival of 58% to 63%.12,13

In an early report of 25 years of OARs, Crawford et al.12 reported survival of 63% at 5 years postoperatively. As in the present study, coronary disease and age were

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**Table III. A, Risk factors for long-term mortality after abdominal aortic aneurysm (AAA) repair**

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major criteria</td>
<td></td>
</tr>
<tr>
<td>Unstable angina or recent MI</td>
<td>4</td>
</tr>
<tr>
<td>Age ≥80 years</td>
<td>3</td>
</tr>
<tr>
<td>Oxygen-dependent COPD</td>
<td>3</td>
</tr>
<tr>
<td>eGFR &lt;30 mL/min/1.73 m²</td>
<td>3</td>
</tr>
<tr>
<td>Minor criteria</td>
<td></td>
</tr>
<tr>
<td>Age 75-79 years</td>
<td>2</td>
</tr>
<tr>
<td>Prior MI</td>
<td>1</td>
</tr>
<tr>
<td>Stable angina</td>
<td>1</td>
</tr>
<tr>
<td>Not taking aspirin</td>
<td>1</td>
</tr>
<tr>
<td>Not taking statin</td>
<td>1</td>
</tr>
</tbody>
</table>

COPD, Chronic obstructive pulmonary disease; MI, myocardial infarction; eGFR, estimated glomerular filtration rate.

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**Table III. B, Designation of low-risk, medium-risk, and high-risk patients for long-term mortality after abdominal aortic aneurysm (AAA) repair**

<table>
<thead>
<tr>
<th>Risk</th>
<th>Determined by</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low risk</td>
<td>No major risk factors or 1-2 minor risk factors, or both</td>
</tr>
<tr>
<td>Medium risk</td>
<td>1 major risk factor or 3-4 minor risk factors</td>
</tr>
<tr>
<td>High risk</td>
<td>2 major risk factors or 1 major risk factor and ≥3 minor risk factors</td>
</tr>
</tbody>
</table>

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CI, Confidence interval; COPD, chronic obstructive pulmonary disease; eGFR, estimated glomerular filtration rate; HR, hazard ratio; MI, myocardial infarction; OR, odds ratio.
correlated with worse survival. The authors suggested that advanced age and life-limiting comorbidities give pause to otherwise proceeding with elective repair of AAA and that improvement in long-term survival after OAR would be a result of better patient selection. Debakey et al demonstrated similar findings. Survival was greatest in those with no hypertension or cardiovascular disease (74% vs 51%) at 5 years. In our series, survival was improved in those without hypertension or coronary disease compared with those with these conditions, but not to the extent of prior reports (77% vs 82% at 5 years). This highlights the effect on survival from other comorbid conditions, such as COPD and renal disease, in contemporary practice.

Two plausible explanations for our improved 5-year survival after AAA repair compared with these prior historic reports include better patient selection and improved perioperative and postoperative management. Surgeons in this cohort may have avoided patients at high risk for subsequent early death from associated comorbidities. Because we found that EVAR is more often applied to high-risk patients, this may also be a differentiating factor compared with these early reports of only OAR.

The second explanation is that perioperative and postdischarge medical management has improved greatly in recent decades. Overall trends for the past decade demonstrated a decline in perioperative AAA repair mortality rates in the United States and in other countries. This has been greatly influenced by the lower perioperative mortality rate of EVAR. In addition, the adoption of evidence-based measures, such as perioperative β-blockade, has been shown to reduce mortality after AAA repair.

Furthermore, within the present study, preoperative aspirin and statin use was associated with improved 5-year survival. In VSGNE, 52% of patients were discharged with both statin and antiplatelet therapy after AAA repair, which is likely much higher than in historical comparison studies.

The use of aspirin in patients with atherosclerotic disease for secondary and tertiary prevention of cardiovascular events is well established. However, there are no published data for a survival benefit of aspirin therapy in patients after AAA repair, and aspirin is not included within the current Society for Vascular Surgery practice guidelines for care of patients with AAA. A recent Danish epidemiologic study demonstrated that AAA patients have a higher incidence of cardiac and cerebrovascular events, as well as overall mortality, compared with the general population.
population. Thus, our finding of improved survival with aspirin use may be due to prevention of cardiovascular events in this high-risk population. This suggests that the care of patients with AAA may be improved with aspirin therapy as a secondary preventative strategy for cardiovascular events.

In contrast, statin use is recommended as medical management for patients with AAA. Our finding that statin use was associated with improved 5-year survival is consistent with other reports. A recent meta-analysis of nearly 12,000 patients after AAA repair demonstrated a beneficial effect of statin use in long-term survival (HR, 0.57) up to 5 years. In contrast to age and other comorbid conditions, aspirin and statin use represent a potentially modifiable risk factor that can improve survival. In the context of the available evidence, our data are consistent with the hypothesis that optimal cardiovascular medical management, including aspirin and statin use in AAA patients, will improve survival due to prevention of late cardiovascular events.

The present study has several limitations. Our analysis is retrospective and based on patients selected for AAA repair. Thus, a portion of high-risk AAA patients who were not offered surgery is not represented. This is consistent with our finding that only 4% of patients were “high-risk.” The creation of disease-based registries, compared with procedural-based registries, may offer the ability for these types of comparisons in the future.

In addition, we sought to create a clinically relevant method for risk stratification of patients undergoing AAA repair. This is based on the contribution of risk factors in our multivariable model. Although our specific thresholds for low risk, medium risk, or high risk may be open to debate, our stratification has clinical and face validity because the major drivers of 5-year mortality have been demonstrated previously. Our present stratification system for predicting 5-year survival provides an appropriate background for patient assessment and selection that must also include assessment of risks and benefits of repair. This will include factors that may increase the risk of rupture, such as the presence of COPD, as well as the adjustment of modifiable risk factors to optimize survival after repair. Validation of our survival risk score requires testing in additional patients in the future.

CONCLUSIONS

These data suggest that survival after AAA repair is good in contemporary practice and appears to be better than in historical series. Factors such as advanced age, cardiac disease, oxygen-dependent COPD, and an eGFR <30 mg/mL/1.73 m² are major risk factors associated with 5-year mortality in patients undergoing AAA repair in our region. Conversely, aspirin and statin use were associated with improved survival. Patients with very high comorbidity profiles may have <50% 5-year survival, and repair can only be beneficial if rupture risk is assessed as very high. Efforts at improved medical management in patients after AAA repair may improve survival by preventing cardiovascular events.

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AUTHOR CONTRIBUTIONS

Conception and design: RD, PG, DS, JC
Analysis and interpretation: RD, PG, BN, AF, VP, DS, JC
Data collection: RD, PG, BN, WR, AR, AF, VP, DS, JC
Writing the article: RD, PG, BN, WR, AR, AF, DS, JC
Critical revision of the article: RD, PG, BN, WR, AR, AF, VP, DS, JC
Final approval of the article: RD, PG, BN, WR, AR, AF, VP, DS, JC
Statistical analysis: RD, PG, BN, VP
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