Risk Prediction for Adverse Events After Carotid Artery Stenting in Higher Surgical Risk Patients

Neil J. Wimmer, MD; Robert W. Yeh, MD, MSc; Donald E. Cutlip, MD; Laura Mauri, MD, MSc

Background and Purpose—The goal of carotid artery stenting is to decrease the risk of stroke or other adverse events from carotid artery disease. Choosing a treatment strategy requires patient-specific information regarding periprocedural risk of adverse neurologic events. The aim of this study was to predict individual patient risk after carotid artery stenting in patients at higher risk for carotid endarterectomy.

Methods—Subjects enrolled in the Stenting and Angioplasty with Protection in Patients at High-Risk for Endarterectomy (SAPPHIRE) worldwide study underwent carotid artery stenting with distal protection. Only patients with at least 1 anatomic or comorbid factor associated with elevated surgical risk were included. Preprocedural factors were used to develop a model and integer-based risk score predicting stroke or death within 30 days. The model was calibrated and internally validated using bootstrap resampling.

Results—Ten thousand one hundred eighty-six patients were included in the analysis. The overall rate of stroke or death was 3.6% at 30 days after carotid artery stenting. Independent predictors of adverse outcomes were increased age ($P=0.006$), history of stroke ($P<0.001$), history of transient ischemic attack presentation ($P=0.001$), recent (<4 weeks) myocardial infarction ($P=0.006$), dialysis treatment ($P=0.007$), need for cardiac surgery in addition to carotid revascularization ($P=0.005$), a right-sided carotid stenosis ($P=0.006$), a longer carotid plaque ($P=0.012$), the presence of a Type II or III aortic arch ($P=0.035$), and a tortuous carotid arterial system ($P=0.004$). The optimism-adjusted C-statistic was 0.691.

Conclusions—Commonly collected clinical and anatomic variables can identify patients at high and low risk for stroke or death after carotid artery stenting. (Stroke. 2012;43:000-000.)

Key Words: carotid arteries ■ risk factors ■ stenting ■ stents
previously published risk scores, however, are specifically applicable to higher surgical risk patients. Previous risk scores also were not developed in cohorts in which outcomes were evaluated using independent clinical end point committees.

The Stenting and Angioplasty with Protection in Patients at High-Risk for Endarterectomy (SAPPHIRE) randomized trial is the only randomized clinical trial to specifically enroll higher surgical risk patients for the comparison of CEA and CAS using modern techniques with embolic protection.20 However, with only 334 patients, there was not sufficient data to determine what features were strongly associated with peri-procedural risk.

The goal of this study is to develop and internally validate a model and bedside tool to predict death or stroke within 30 days of CAS in higher surgical risk patients using easily collected variables that can be assessed in routine clinical practice. The study population is drawn from the SAPPHIRE worldwide study, a single-arm prospective study of higher risk patients undergoing CAS with embolic protection. The prediction model generated here can be used to support decision-making.

Methods

Study Population and Measurements

The SAPPHIRE worldwide study has been described.21 Patients were enrolled from 364 centers across the United States and Canada. Patients were required to have either ≥50% carotid stenosis (determined by ultrasound or angiogram) if symptomatic (transient ischemic attack or stroke within 180 days) or ≥80% carotid stenosis if asymptomatic. Patients were required to have at least 1 factor that made them higher risk for CEA as determined by the enrolling physician. High-risk criteria include: age ≥75 years, Class III or IV New York Heart Association heart failure or left ventricular ejection fraction <50%, open heart surgery within 6 weeks, recent myocardial infarction within 4 weeks, unstable angina (Canadian Cardiovascular Society Class I, II, or III), the presence of significant aortic arch calcification, significant common carotid artery or internal carotid artery tortuosity, anatomic and angiographic factors including the type of aortic arch (I, II, or III), the presence of significant aortic arch calcification, significant common carotid artery lesion below the clavicle). We also considered anatomic and angiographic factors including the type of aortic arch (I, II, or III), the presence of significant aortic arch calcification, significant common carotid artery or internal carotid artery tortuosity, lesion calcification, lesion length, the presence of lesion ulceration, with the study device. Operators participated in a training program tailored to previous procedural volume and experience with study devices.22

Patients were evaluated at baseline, hospital discharge, and 30 days postprocedure. The baseline evaluation included a carotid ultrasound, angiogram, or both. The National Institutes of Health Stroke Scale and the modified Rankin Scale were performed by certified providers but not necessarily neurologists. Adverse events were assessed up to 30 days postprocedure. An independent Clinical Events Committee at the Harvard Clinical Research Institute, Boston, MA, adjudicated all major adverse events including stroke. Remote data monitoring of all end points was conducted in all patients, whereas onsite monitoring by review of medical records was conducted in approximately 15% of patients. The SAPPHIRE worldwide study is sponsored by Cordis. The authors, who had full access to the data, performed the analysis and did not receive funding from Cordis for the analysis.

Candidate Predictors

Stroke was defined as a nonconvulsive, focal neurologic deficit of abrupt onset persisting for >24 hours with the deficit corresponding to a vascular territory.

We identified a list of variables to be considered in the multivariable model based on clinical relevance. These included sociodemographic information (age, sex, and race/ethnicity), medical history (hypertension, diabetes mellitus, dyslipidemia, hemorrhagic, or acute pulmonary disease), cardiovascular and neurovascular history (prior coronary artery disease, prior myocardial infarction, prior stroke, prior transient ischemic attack, prior coronary artery bypass grafting, prior carotid endarterectomy, prior peripheral angioplasty or stenting, prior heart failure, whether the carotid lesion was symptomatic), and factors associated with increased risk for CEA (low left ventricular ejection fraction or New York Heart Association Class III or IV heart failure, recent or planned heart surgery within 6 weeks, myocardial infarction within 4 weeks, recent unstable angina, severe pulmonary disease, a significantly abnormal cardiac stress test, age ≥75 years, contralateral carotid artery occlusion, contralateral laryngeal nerve palsy, history of neck radiation, tandem carotid lesions, previous CEA recurrent stenosis, or internal carotid artery lesion or a low common carotid artery lesion below the clavicle). We also considered anatomic and angiographic factors including the type of aortic arch (I, II, or III), the presence of significant aortic arch calcification, significant common carotid artery or internal carotid artery tortuosity, lesion calcification, lesion length, the presence of lesion ulceration,

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean (±SD) or Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>72.3 ± 9.7</td>
</tr>
<tr>
<td>Male</td>
<td>61.1%</td>
</tr>
<tr>
<td>Symptomatic</td>
<td>29.8%</td>
</tr>
<tr>
<td>White</td>
<td>91.6%</td>
</tr>
<tr>
<td>Hypertension</td>
<td>82.3%</td>
</tr>
<tr>
<td>Diabetes</td>
<td>32.7%</td>
</tr>
<tr>
<td>Prior myocardial infarction</td>
<td>19.3%</td>
</tr>
<tr>
<td>Prior carotid endarterectomy</td>
<td>27.8%</td>
</tr>
<tr>
<td>History of stroke</td>
<td>22.5%</td>
</tr>
<tr>
<td>History of TIA</td>
<td>22.7%</td>
</tr>
<tr>
<td>History chronic kidney disease (creatinine &gt;2.5 mg/dL)</td>
<td>5.1%</td>
</tr>
<tr>
<td>Dialysis</td>
<td>1.4%</td>
</tr>
</tbody>
</table>

Total number of patients=10 186.
TIA indicates transient ischemic attack.
Table 2. High-Risk Characteristics for Carotid Endarterectomy

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Percentage of Total Subjects (n=10,186)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiologic high-risk characteristic</td>
<td></td>
</tr>
<tr>
<td>CHF (Class III or IV) or LVEF ≤30%</td>
<td>11.0%</td>
</tr>
<tr>
<td>Heart surgery in 6 weeks</td>
<td>0.9%</td>
</tr>
<tr>
<td>MI within 4 weeks</td>
<td>1.7%</td>
</tr>
<tr>
<td>Unstable angina</td>
<td>4.2%</td>
</tr>
<tr>
<td>Severe pulmonary disease</td>
<td>12.2%</td>
</tr>
<tr>
<td>Abnormal stress test</td>
<td>10.6%</td>
</tr>
<tr>
<td>Age &gt;75 y</td>
<td>39.8%</td>
</tr>
<tr>
<td>Severe simultaneous cardiac disease requiring surgery and carotid disease</td>
<td>3.8%</td>
</tr>
<tr>
<td>Anatomic high-risk characteristic</td>
<td></td>
</tr>
<tr>
<td>Contralateral occlusion</td>
<td>13.0%</td>
</tr>
<tr>
<td>Contrainlateral laryngal palsy</td>
<td>0.5%</td>
</tr>
<tr>
<td>Postneck radiation</td>
<td>7.1%</td>
</tr>
<tr>
<td>Tandem lesions</td>
<td>2.5%</td>
</tr>
<tr>
<td>High ICA or CCA lesions below clavicle</td>
<td>10.4%</td>
</tr>
<tr>
<td>Previous CEA recurrent stenosis</td>
<td>23.1%</td>
</tr>
</tbody>
</table>

CHF indicates congestive heart failure; LVEF, left ventricular ejection fraction; MI, myocardial infarction; ICA, internal carotid artery; CCA, common carotid artery; CEA, carotid endarterectomy.

Statistical Analysis

We first examined the univariate associations of a composite end point of stroke or death at 30 days with all candidate variables. Next, multivariable logistic regression was performed using candidates with univariate P<0.2. We performed backward elimination of candidates until only variables with P<0.05 remained. Age and lesion length were entered as linear functions based on their monotonic relationships with the end point.

Internal validation and calibration were performed using bootstrapping (resampling with replacement) techniques.23 We generated 1000 bootstrap samples with repetition of the variable selection procedure and the final model coefficients were adjusted based on a linear calibration slope.24 We assessed discrimination as measured by the C-statistic and calibration based on comparing observed and predicted event rates across deciles of predicted risk over bootstrapped samples. We also adjusted the reported model discrimination based on bootstrap methods to adjust for model optimism and overfitting. The adjusted C-statistic was calculated: adjusted performance=apparent performance in the original sample–average(bootstrap model performance in bootstrap sample–bootstrapped model performance in original sample).25

The β coefficients from the model were used to generate point scores for an integer-based tool.26

Given previous literature relating operator experience to outcomes with CAS,27,28 we evaluated whether the addition of operator experience (coded as a binary variable of >25 procedures as the primary operator and >10 using the study devices or >25 procedures as the primary or secondary operator and >13 as the primary operator) improved the final model based on likelihood ratio testing and based on the calculation of the integrated discrimination improvement index.29

Analyses were performed using STATA 11.2 (Statacorp, College Station, TX).

Results

The study population included 10,186 patients who underwent CAS with distal protection between October 30, 2006, and September 30, 2010. Mean age was 72.3±9.7 years, and 38.9% of patients were women. History of stroke was present in 22.5% of patients and history of transient ischemic attack in 22.7%. Symptomatic carotid lesions were present in 29.8% of patients (Table 1). The most common high surgical risk feature for CEA was age ≥75 years. The frequency of other high surgical risk features is in Table 2. Successful use of the study embolic protection device occurred in 96.4% of patients.

Death occurred in 123 patients (1.2%) and stroke in 301 (3.0%) within 30 days of CAS. A total of 366 patients had either stroke or death within 30 days. Two hundred forty-five strokes were ipsilateral (79.5% of strokes) and 276 were ischemic (91.7%). Lacunar strokes occurred in 33 subjects (11.9% of ischemic strokes). There were 25 hemorrhagic strokes.

The final multivariable model with calibration slope-adjusted coefficients is presented in Table 3. There are 10 significant predictors in the final model. The raw C-statistic

Table 3. Final Logistic Regression Model for Death or Stroke at 30 D After Carotid Artery Stenting

<table>
<thead>
<tr>
<th>Variable</th>
<th>Adjusted Beta</th>
<th>Adjusted OR</th>
<th>95% CI for Adjusted OR</th>
<th>PValue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age per 10 y</td>
<td>0.417</td>
<td>1.520</td>
<td>1.32–1.81</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Stroke</td>
<td>0.731</td>
<td>2.080</td>
<td>1.55–2.75</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Transient ischemic attack</td>
<td>0.534</td>
<td>1.710</td>
<td>1.24–2.22</td>
<td>0.001</td>
</tr>
<tr>
<td>Myocardial infarction within 4 wk</td>
<td>1.025</td>
<td>2.790</td>
<td>1.34–5.62</td>
<td>0.006</td>
</tr>
<tr>
<td>Dialysis</td>
<td>0.986</td>
<td>2.680</td>
<td>1.34–6.01</td>
<td>0.007</td>
</tr>
<tr>
<td>Need for concomitant cardiac surgery plus carotid revascularization</td>
<td>0.772</td>
<td>2.160</td>
<td>1.27–3.77</td>
<td>0.005</td>
</tr>
<tr>
<td>Left-sided lesion</td>
<td>−0.385</td>
<td>0.680</td>
<td>0.51–0.99</td>
<td>0.006</td>
</tr>
<tr>
<td>Lesion length per 10 mm</td>
<td>0.183</td>
<td>1.200</td>
<td>1.03–1.33</td>
<td>0.012</td>
</tr>
<tr>
<td>Type II or Type III aortic arch</td>
<td>0.291</td>
<td>1.240</td>
<td>1.02–1.49</td>
<td>0.035</td>
</tr>
<tr>
<td>Two 90° bends</td>
<td>0.463</td>
<td>1.590</td>
<td>1.17–2.21</td>
<td>0.004</td>
</tr>
<tr>
<td>Constant</td>
<td>−7.350</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The optimism-adjusted C-statistic=0.691. The associated Hosmer-Lemeshow P=0.62.
was 0.709 and the optimism-adjusted C-statistic is 0.691. Over 100 bootstrapped samples, the predicted probability of death or stroke within 30 days was well calibrated with the observed rates of death or stroke (Figure 1; Hosmer-Lemeshow $P=0.62$).

An integer-based tool intended for bedside use is shown in Figure 2. Individuals with ≤8 points have a predicted risk of death or stroke of <3% at 30 days. The C-statistic of the integer-based score is 0.683. Individuals with >12 points have a predicted rate of death or stroke >6%. We also demonstrate that the rate of observed events was similar to the rate of events predicted based on the bedside tool (Figure 3).

The addition of 2 different binary variables for operator experience did not significantly improve the final model based on likelihood ratio testing or based on calculation of the integrated discrimination improvement (0.00027, $P=0.45$ or 0.00030, $P=0.49$).

**Discussion**

In a large study of patients at higher risk for CEA, commonly collected variables were able to identify patients at high and low risk for stroke or death after CAS. We generated a risk model and simple risk score to predict stroke or death within 30 days using these variables. We found that elevated age, history of stroke, history of transient ischemic attack, recent myocardial infarction, the need for both cardiac surgery and carotid revascularization, dialysis treatment, the presence of a Type II or III aortic arch, a right-sided carotid stenosis, a longer carotid plaque, and a severely tortuous carotid arterial system were all important risk factors for the development of stroke or death within 30 days of CAS. These findings are consistent with previous observations regarding the risk factors for adverse events associated with CAS.10–31 Our findings also reinforce that in addition to comorbid conditions, anatomic and lesion-specific considerations simultaneously confer risk and should be factored into the decision about carotid revascularization with CAS.

Our study differs from previous studies that have considered CAS risk prediction17–19 and represents an improvement in a number of ways. First, we were able to use data from many centers across the spectrum of clinical practice. Our study used routine, impartial clinical end point adjudication and the administration of standard stroke assessment tools not available in previous studies that generated risk models. Most importantly, however, our study is restricted to higher surgical risk patients who were not well represented in the original surgical studies that led to the adverse event rate thresholds that are present in the multisociety guidelines.35–38 Nonrandomized studies have demonstrated higher rates of adverse events with CEA in patients with multiple risk factors.10,11,39 In routine clinical practice, clinicians are currently referring patients with more severe comorbid conditions to CAS rather than to CEA more frequently.40 Thus, even without adequate tools to precisely predict the risk of adverse events after CAS for high surgical risk patients, clinicians are more likely to refer the most severely ill patients to CAS rather than to CEA. The risk prediction model presented here will now allow clinicians to assess CAS risk in a more quantitative manner than previously possible.

Our analyses should be interpreted in the context of important limitations. Although we retained a large number of clinically relevant variables in our model, the discriminative ability of the model was modest. Whereas our reported discrimination compares favorably with the discrimination of previously reported models, there may be unobserved social, biological, or procedural factors associated with stroke or death after CAS that are not accounted for in our models. We also are limited by the fact that not every patient was subject to evaluation by a neurologist to ascertain the end point of stroke. Although certified study coordinators administered standard assessment tools, ascertainment of postprocedure complications may be lower than if neurologists performed routine assessments. We are also limited by self-reporting of anatomic and lesion-specific considerations simultaneously.

![Figure 1](http://stroke.ahajournals.org/). **Figure 1.** Observed versus predicted probability of death or stroke within 30 days with the full model over 100 bootstrapped samples. Individuals are grouped into 10 deciles based on their predicted probability of death or stroke in 30 days. Displayed line is $y=x$. Although our risk score quantifies the risk for individuals contemplating CAS, a particular score for a given individual does not imply that CAS is appropriate therapy. There remain major controversies, specifically with regard to the role of medical therapy alone, in this population. The role of medical therapy alone is particularly important to study in elderly patients, in those with significant comorbidities, and in asymptomatic patients.
Conclusions
We developed and validated a predictive model and integer-based tool to predict the occurrence of death or stroke within 30 days of CAS. The prospective use of individualized assessments may support rational decision-making for the treatment of carotid atherosclerosis and may aid communication between clinicians and patients before CAS. In the future, prospective testing should be performed to ascertain whether this model improves patient outcomes and understanding.

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Disclosures
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Figure 2. Bedside prediction tool for death or stroke at 30 days after carotid artery stenting. The total point score gives the predicted probability for death or stroke at 30 days according to the following equation:

\[ \text{Death or stroke at 30 days} = \frac{1}{1 + \exp\left(-5.38 + (0.21 \times \text{total points})\right)}. \]

TIA indicates transient ischemic attack; MI, myocardial infarction.
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Wimmer et al

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7
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