Background and Purpose—Carotid artery stenosis causes up to 10% of all ischemic strokes. Carotid endarterectomy (CEA) was introduced as a treatment to prevent stroke in the early 1950s. Carotid stenting (CAS) was introduced as a treatment to prevent stroke in 1994.

Methods—The Carotid Revascularization Endarterectomy versus Stenting Trial (CREST) is a randomized trial with blinded end point adjudication. Symptomatic and asymptomatic patients were randomized to CAS or CEA. The primary end point was the composite of any stroke, myocardial infarction, or death during the periprocedural period and ipsilateral stroke thereafter, up to 4 years.

Results—There was no significant difference in the rates of the primary end point between CAS and CEA (7.2% versus 6.8%; hazard ratio, 1.11; 95% CI, 0.81 to 1.51; \( P = 0.51 \)). Symptomatic status and sex did not modify the treatment effect, but an interaction with age and treatment was detected (\( P = 0.02 \)). Outcomes were slightly better after CAS for patients aged <70 years and better after CEA for patients aged >70 years. The periprocedural end point did not differ for CAS and CEA, but there were differences in the components, CAS versus CEA (stroke 4.1% versus 2.3%, \( P = 0.012 \); and myocardial infarction 1.1% versus 2.3%, \( P = 0.032 \)).

Conclusions—In CREST, CAS and CEA had similar short-and longer-term outcomes. During the periprocedural period, there was higher risk of stroke with CAS and higher risk of myocardial infarction with CEA.

Clinical Trial Registration—www.clinicaltrials.gov. Unique identifier: NCT00004732.

Key Words: carotid endarterectomy ■ carotid stenosis ■ randomized controlled trials ■ stenting ■ stroke care
new ST segment depression or elevation >1 mm in ≥2 contiguous leads (as determined by the centralized core laboratory).13

Analysis was intention to treat. Proportional hazards analysis adjusting for age, sex, and symptomatic status was used to test for treatment differences.

Secondary aims were analyzed by including interaction terms in the proportional hazards models.

Results

For a total of 2502 participants (Table 1), there was no significant difference in the primary end point between CAS and CEA (7.2% versus 6.8%; hazard ratio, 1.11; 95% CI, 0.81 to 1.51; P=0.51; Table 2). During the periprocedural period, the incidence of the primary end point was similar for CAS and CEA, but there were differences in the end point components (stroke 4.1% versus 2.3%, P=0.012; MI 1.1% versus 2.3%, P=0.032; and death 0.7% versus 0.3%, P=0.18). Thereafter, ipsilateral stroke was infrequent for both CAS and CEA (2.0% versus 2.4%, P=0.85).

Neither symptomatic status nor sex showed an effect on treatment difference per preplanned effect modification analyses. Patient age did interact with treatment efficacy (P=0.02). Outcomes were slightly better after CAS for patients aged <70 years and better after CEA for patients aged ≥70 years.

During the periprocedural period, the occurrence of the primary end point components (stroke, MI, or death) for CAS and CEA was not different for symptomatic (6.7% versus 5.4%; hazard ratio, 1.26; 95% CI, 0.81 to 1.96) or asymptomatic subjects (3.5% versus 3.6%; hazard ratio, 1.02; 95% CI, 0.55 to 1.86). The risk of stroke and death was significantly higher for CAS in symptomatic patients (6.0% versus 3.2%; hazard ratio, 1.89; 95% CI, 1.11 to 3.21), but not for asymptomatic patients (2.5% versus 1.4%; hazard ratio, 1.88; 95% CI, 0.79 to 4.42); however, a smaller total number of events occurred in the asymptomatic strata, resulting in lower statistical power to detect treatment differences. Cranial nerve palsies were less frequent for CAS (0.3% versus 4.7%; hazard ratio, 0.07, 95% CI, 0.02 to 0.18). At 1 year, periprocedural major and minor stroke had an effect on the physical component

Table 1. Selected Characteristics of the Study Cohort by Treatment Group

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>CAS (N=1262)</th>
<th>CEA (N=1240)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, years*</td>
<td>68.9±9.0</td>
<td>69.2±8.7</td>
</tr>
<tr>
<td>Male sex, % of patients</td>
<td>63.9</td>
<td>66.4</td>
</tr>
<tr>
<td>Asymptomatic arteries, % of patients</td>
<td>47.1</td>
<td>47.3</td>
</tr>
<tr>
<td>Risk factors, % of patients</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>85.8</td>
<td>86.1</td>
</tr>
<tr>
<td>Diabetes</td>
<td>30.6</td>
<td>30.4</td>
</tr>
<tr>
<td>Dyslipidemia†</td>
<td>82.9</td>
<td>85.8</td>
</tr>
<tr>
<td>Current smoker</td>
<td>26.4</td>
<td>26.1</td>
</tr>
<tr>
<td>Percent stenosis at randomization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Severe (≥70%)</td>
<td>86.9</td>
<td>85.1</td>
</tr>
<tr>
<td>Median time from randomization to treatment (no. of days)</td>
<td>6</td>
<td>7</td>
</tr>
</tbody>
</table>

*Means±SD. †P=0.05 for the difference in the baseline rate of dyslipidemia between the 2 groups.

Institutes of Health Stroke Scale, and Transient Ischemic Attack Stroke Questionnaire were performed at 18 to 54 hours; and an electrocardiogram was obtained at 6 to 48 hours and at 1 month. The National Institutes of Health Stroke Scale, modified Rankin Scale, and carotid ultrasound were also performed at 1, 6, and 12 months and annually thereafter.8 A telephone follow-up call was performed at 3 months and every 6 months thereafter. The Medical Outcomes Study 36-item Short Form Instrument was performed at 18 to 54 hours; and an electrocardiogram was obtained at 6 to 48 hours and at 1 month. The National Institutes of Health Stroke Scale, modified Rankin Scale, and Transient Ischemic Attack Stroke Questionnaire were performed at 18 to 54 hours; and an electrocardiogram was obtained at 6 to 48 hours and at 1 month. The National Institutes of Health Stroke Scale, modified Rankin Scale, and Transient Ischemic Attack Stroke Questionnaire were performed at 18 to 54 hours; and an electrocardiogram was obtained at 6 to 48 hours and at 1 month. The National Institutes of Health Stroke Scale, modified Rankin Scale, and Transient Ischemic Attack Stroke Questionnaire were performed at 18 to 54 hours; and an electrocardiogram was obtained at 6 to 48 hours and at 1 month. The National Institutes of Health Stroke Scale, modified Rankin Scale, and Transient Ischemic Attack Stroke Questionnaire were performed at 18 to 54 hours; and an electrocardiogram was obtained at 6 to 48 hours and at 1 month.

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Table 2. Composite Primary End Point and Components of the Primary End Point

<table>
<thead>
<tr>
<th>4-Year Study Period (Including Periprocedural Period)*</th>
<th>No. of Patients (%±SE)</th>
<th>Absolute Treatment Effect of CAS Versus CEA (95% CI) Percentage Points P†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stroke</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any stroke</td>
<td>105 (10.2±1.1)</td>
<td>75 (7.9±1.0)</td>
</tr>
<tr>
<td>Major ipsilateral stroke</td>
<td>16 (1.4±0.3)</td>
<td>6 (0.5±0.2)</td>
</tr>
<tr>
<td>Minor ipsilateral stroke</td>
<td>52 (4.5±0.6)</td>
<td>36 (3.5±0.6)</td>
</tr>
<tr>
<td>Primary end point (any periprocedural stroke, myocardial infarction, or death or post procedural ipsilateral stroke)</td>
<td>85 (7.2±0.8)</td>
<td>76 (6.8±0.8)</td>
</tr>
</tbody>
</table>

*For patients who received the assigned procedure within 30 days after randomization, the periprocedural period was defined as the 30-day period after the procedure. For patients who did not receive the assigned procedure within 30 days after randomization, the periprocedural period was defined as the 36-day period after randomization.

†P values were calculated based on significance of the hazard ratios.7
summary scale of the Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36), whereas periprocedural MI did not. Minor stroke had a significant effect on the mental component scale at 1 year.7

Discussion
CAS and CEA had similar net outcomes for symptomatic and asymptomatic men and women. However, there was a lower incidence of MI immediately after CAS and a lower incidence of stroke immediately after CEA.14,15 Exploratory analyses among 1-year survivors with regard to quality of life suggested a sustained effect for stroke but not for MI. In addition, older patients had better outcomes after CEA and younger patients had slightly better outcomes after CAS.16 Consequently, the preferences of the patient and his or her age may be important considerations in choice of treatment for carotid stenosis. The relationship between advancing age and increasing adverse events after CAS has been observed previously,10,5,17 and the effect of advancing age on treatment differences, CAS versus CEA, has been observed in the Stent-Protected Angioplasty versus Carotid Endarterectomy (SPACE) trial.

The periprocedural safety outcomes for CAS and CEA are the best reported to date for patients with pre- and postprocedural medical, neurological, electrocardiogram, and enzyme evaluations. These excellent CREST outcomes may reflect a validated and effective surgeon credentialing process, the rigorous training and credentialing of interventionists, and the increasing assimilation of endovascular expertise.10 Improved and more widely used medical therapies may also account for the better outcomes observed after CEA in CREST compared with outcomes in previous randomized clinical trials of CEA.18–21

Inference from the CREST results should be done in the context of several notable limitations. Changes occurred during the course of the study in preprocedural medical management, CAS and CEA procedural techniques and technology, and in postprocedural medical management. Only 1 stent system was used among several available. The definitions of stroke and MI and methods to detect them have raised questions regarding the importance of stroke or MI for the individual patient. In addition, improvements in the medical treatments for carotid disease have evolved, and CREST did not include a medical arm. Accordingly, the results of landmark trials that favored carotid revascularization (CEA) over medical treatment may or may not be applicable today.

Summary
CAS, when done by experienced and skilled interventionists, has patient outcomes similar to those of CEA done by experienced and skilled surgeons. During the perioperative period, more strokes occur after CAS and more MIs occur after CEA. Younger patients have slightly better outcomes with CAS and older patients have better outcomes with CEA. For the future, both CEA and CAS appear to be useful tools for preventing stroke.

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Disclosures
C.H.T. reports the following: Abbott Vascular, modest, Speakers’ Bureau; Abbott Vascular, modest, Honoraria. T.G.B. reports the following: Sahs Memorial Lecture University of Iowa, modest, Honoraria; VEITH Symposium, modest, Honoraria; American Academy of Neurology 62nd Annual Meeting, modest, Honoraria; Heritage Valley Health System, modest, Honoraria; American Society of Neuroradiology 48th Annual Meeting, modest, Honoraria; Massachusetts General Hospital, modest, Honoraria; Pennsylvania Advances in Stroke, modest, Honoraria. There are no other disclosures to report.

References


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