Surgery vs Stent: Treatment for Carotid Artery Disease
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ABSTRACT

PURPOSE: This article summarizes and compares the roles of surgery and stent in the management of carotid artery disease.

EPIDEMIOLOGY: Carotid endarterectomy (CEA), surgical removal of atherosclerotic plaque, is the most commonly performed vascular procedure in the United States to prevent stroke in patients with carotid artery stenosis, but certain angiographic and medical conditions limit patients' viability as CEA candidates.

REVIEW SUMMARY: Despite its well-demonstrated efficacy, CEA is not without limitations, which include high rates of perioperative complications. The leading alternative to CEA for revascularization of carotid artery disease is carotid artery stent placement. Carotid stenting (CS) is less invasive than CEA and has had favorable outcomes. Refinement of the stenting procedure and the use of distal embolic protection devices has gained regard for stenting as a beneficial alternative to CEA, especially for high-risk patients.

TYPE OF AVAILABLE EVIDENCE: Randomized, multicenter clinical trial; prospective, nonrandomized, multicenter, single-arm study; prospective, randomized, multicenter clinical trial; unstructured review.

GRADE OF AVAILABLE EVIDENCE: Fair to good.

CONCLUSION: Although CEA is a well-established surgical procedure for the treatment of carotid artery disease, its application is limited. Carotid stenting is a relatively less invasive technique for carotid artery revascularization, and when performed with embolic protection devices, it is a beneficial alternative to CEA for certain high-surgical-risk patients.


See editorial on page 433.

More than 700,000 strokes occur in the United States each year.1 Stroke is currently the third most common cause of death, surpassed only by coronary artery disease and cancer.1 Recent trends suggest that the incidence of stroke is increasing, and it may shortly become the second most common cause of death. Stroke is also the leading cause of disability, and the direct and indirect costs of stroke in the United States are approximately $43 billion per year.2 The majority of all strokes occur in the distribution of the carotid arteries. Carotid artery disease is not only the most common cause, but also a preventable cause, of brain infarction.

This article addresses carotid artery disease from a revascularization point of view. It reviews revascularization options of surgery vs stenting and presents information regarding the appropriate primary care approach to carotid artery disease.

Clinical Presentation and Natural History
The recognition and diagnosis of carotid artery...
disease are important to prevent such consequences as transient ischemic attack (TIA) or stroke. When carotid artery stenosis is suspected, the diagnosis is confirmed by a variety of noninvasive tests, such as duplex ultrasound. When the results of duplex ultrasound are inconclusive, magnetic resonance angiography, computed tomographic angiography, or conventional X-ray angiography may be ordered. The demonstration of significant stenosis of the internal carotid artery is a cause for concern, and the patient should be referred for evaluation regarding possible revascularization.

Symptoms related to carotid artery stenosis are classified as TIA or stroke depending on the duration of symptoms. TIA symptoms are self-limited symptoms that completely resolve from within minutes to 24 hours after onset. When symptoms persist longer than 24 hours, stroke has occurred. Symptoms of TIA or stroke may be specific, like mono-ocular blindness (amaurosis fugax), weakness, or abnormal sensation in one side of the body (hemispheric paresis or paresthesia). Occasionally, symptoms are nonspecific, such as confusion, loss of balance, headache, or abnormal vision. A TIA is a warning sign of a future stroke, and an estimated 25% to 30% of TIA patients will develop a stroke within the next 2 years with the maximum risk shortly after initial presentation. Thus, patients with carotid artery stenosis who are manifesting TIA need urgent evaluation to prevent the development of strokes. Suspected strokes should be evaluated immediately for possible life-saving interventions (that are beyond the scope of this article). When carotid artery stenosis is the likely cause of stroke, these patients need evaluation for possible revascularization within a few days or weeks after presentation. Whereas carotid endarterectomy (CEA) is usually not recommended before 4 to 6 weeks after the onset of stroke, carotid stenting (CS) can be performed much sooner and after only a few days of acute stroke.

The 3 major causes of ischemic stroke are cardioembolic disease, lacunar disease, and large-artery disease (represented mainly by carotid artery stenosis). In asymptomatic carotid artery stenosis, Inzitari and his colleagues found that the risk of stroke at 5 years after study entry rose with increasing severity of stenoses. Moreover, they demonstrated that regardless of whether the patient has mild or severe carotid artery disease, carotid artery stenosis brings about more strokes than all other causes of brain infarctions. Although a direct relationship exists between the severity of carotid artery disease and the risk of stroke, the relationship is not present for patients with total carotid artery occlusion, and this fact has the clinical implication that total occlusion of the carotid artery does not usually require revascularization.

The risk of stroke among patients with asymptomatic carotid artery stenosis is relatively low; however, any transition from asymptomatic to symptomatic carotid artery disease is extremely important and signifies a much higher risk of stroke or death. Indeed, for each degree of stenosis, the risk of stroke or death over 5 years more than doubles in symptomatic patients compared to that in patients with asymptomatic carotid artery disease. The major increase in risk occurs within the first 3 to 6 months after the onset of TIA, when the risk of stroke is up to 10 times higher than when a patient remains asymptomatic.

### Measuring Carotid Artery Stenosis

The common carotid artery divides at the carotid bifurcation into the internal carotid artery and the external carotid artery. The internal carotid artery supplies the brain, and the external carotid artery provides blood supply to facial and neck structures. Thus, stenosis in the internal carotid artery is an important cause of brain infarction, and stenosis in the external carotid artery is not. The most frequent cause of carotid artery stenosis is atherosclerosis that affects the proximal part of the internal carotid artery (the carotid bulb). Measuring the degree of carotid artery stenosis is important for planning management, particularly the need and timing of revascularization. Since the carotid bulb is wider than the rest of the internal carotid artery, several methods to calculate degrees of stenosis are available. Of those, the North American Symptomatic Carotid Endarterectomy Trial (NASCET) and the European Carotid Surgery Trial (ECST) are the most commonly used methods. While all methods agree on how to measure the minimal lumen diameter, the narrowest diameter across stenosis, they disagree on the reference diameter (Figure 1). The NASCET method considers the reference to be the normal diameter of the internal carotid artery just distal to stenosis, and the ECST method considers the reference to be the estimated diameter of the carotid bulb. As a result, the different methods provide different interpretations of the same lesion, as shown in Table 1. The NASCET criterion is the main method of measuring carotid stenoses across the United States and will be used throughout this review unless specified otherwise.

### Carotid Endarterectomy

Fifty years ago, CEA—a surgical procedure that involves making an incision in the skin over the carotid artery, opening the artery, removing the carotid atherosclerotic plaque, and closing the artery—was introduced as a logical method for preventing ischemic stroke distal to carotid artery stenosis. The frequency of this procedure grew substantially in the 1970s and 1980s. In 1971, 15,000 CEAs were performed in the United States; by 1985, the frequency had increased at least 7-fold to more than 100,000 procedures. Currently, more than 125,000 CEA procedures are performed annually in the United States, making it the...
most commonly performed surgical procedure to prevent stroke.\(^1\) Surgeons performed CEA in a variety of stenosis conditions with considerable variability in surgical outcomes. This variability set the stage for several randomized clinical trials to address the role of CEA in the management of carotid artery disease.

**Symptomatic Patients**

One of the first large randomized clinical trials that showed a benefit from CEA was the NASCET. This investigation sought to determine whether CEA could reduce the risk of stroke among patients with recent adverse cerebrovascular events and ipsilateral carotid stenosis. It was conducted at 50 centers in the United States and Canada. Patients younger than 80 years with degrees of stenosis ranging from 30% to 99% were randomized to receive optimal medical treatment only, or medical plus surgical treatment (ie, CEA). The first results from this study were published in 1991 and concerned a group of 659 patients with severe stenosis (70%-99%). All of these subjects had had a hemispheric or retinal TIA or a nondisabling stroke within 120 days of randomization. Over a 2-year follow-up period, patients who underwent CEA showed a decreased risk of ipsilateral stroke, from 26% risk among the medical patients to 9% among the surgical patients, a 17% absolute risk reduction and a 65% relative risk reduction. Moreover, the risk of more serious outcomes such as death and disabling stroke decreased over 2 years from 13.1% to 2.5%, an absolute risk reduction of 10.6%, and a relative risk reduction of 81%. Additionally, this study showed that the benefits of CEA are related to the degree of stenosis. For example, patients with 90% stenosis received substantially greater benefits than those patients with 70% stenosis. Benefits were seen in both men and women. The researchers concluded that CEA is highly beneficial to patients with recent hemispheric and retinal TIs, or to those with nondisabling strokes and ipsilateral high-grade stenosis (70%-99%) of the internal carotid artery.\(^5\)

After demonstrating the benefits of CEA in severe carotid artery stenosis, the NASCET group continued to assess the benefit of CEA in more than 2000 subjects with symptomatic mild to moderate stenoses, defined as stenosis of less than 70%. Patients were divided into 2 groups: one group had moderate stenosis (50%-69%) and the other group had mild stenosis (<50%). Over a 5-year follow-up period, the risks of ipsilateral stroke among patients with moderate stenosis were 22% for those who received medical treatment only and 15.5% for patients who received medical treatment plus CEA—an absolute risk reduction of 6.5%, and a relative risk reduction of 29%. The patients with mild stenosis did not benefit from CEA, and the risk of ipsilateral stroke was not significantly different in those patients who received medical treatment only compared to those who received medical treatment plus CEA. The researchers concluded that CEA delivers no benefit for symptomatic patients with stenoses of less than 50% and moderate benefit for patients with symptomatic carotid stenoses of 50% to 69%.\(^6\)

The results seen in the ECST were similar to those of the NASCET. This randomized clinical trial included more than 3000 patients of all ages who were found to have an ipsilateral stenotic lesion in the carotid artery after a nondisabling ischemic stroke, TIA, or retinal infarction. Stenoses were categorized into 3 groups, according to severity: 0% to 29%, 30% to 69%, and 70% to 99% diameter stenoses. Among the patients with less than 70% stenosis, there was no benefit from CEA in terms of a decrease in the risk of stroke; however, CEA decreased the risk of ipsilateral stroke or death by 39% and decreased the risk of major stroke or death by 45% over a 3-year follow-up period in patients with 70% to

![Figure 1. Measuring Carotid Artery Stenosis](image-url)

**Table 1. Degrees of Carotid Stenosis as Measured by Different Methods*\(^*\)**

<table>
<thead>
<tr>
<th>NASCET Method, %</th>
<th>ECST Method, %</th>
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<tr>
<td>90</td>
<td>97</td>
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<td>70</td>
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* Different methods provide different interpretations for the same lesion.
more, when the patients' general health makes them selected asymptomatic patients with stenosis of 60% or investigators' conclusion was that CEA is indicated for women did not appear to receive benefit from CEA. The improvement in the risks of major stroke or death, and reduction of 53%. On the other hand, there was no medical treatment only, an aggregate risk over 5 years for ipsilateral stroke, any perioperative stroke, or death was found to be 5.1% for patients who received medical treatment alone or medical treatment plus surgery, and 11.0% for patients who received medical treatment only, an aggregate risk reduction of 53%. On the other hand, there was no improvement in the risks of major stroke or death, and women did not appear to receive benefit from CEA. The investigators' conclusion was that CEA is indicated for selected asymptomatic patients with stenosis of 60% or more, when the patients' general health makes them good candidates for elective surgery. 10

Another way of looking at the benefit of CEA is to consider how many patients must be treated with CEA to prevent an ipsilateral stroke, a major stroke, or a death. For severe symptomatic carotid artery disease, defined as 70% to 99% diameter stenosis, treating 6 patients with CEA will theoretically prevent 1 ipsilateral stroke over 2 years, and treating 10 patients will prevent 1 major stroke or death over 2 years. For a lesser degree of symptomatic stenosis, from 50% to 69%, treating 12 men with CEA will prevent 1 ipsilateral stroke, and treating 16 men will prevent 1 major stroke or death over 5 years (the benefits of CEA in this group are less certain among women). 6 Finally, for asymptomatic carotid artery disease with at least 60% stenosis, treating 17 men will prevent 1 ipsilateral stroke, perioperative stroke, or death over 5 years (as stated above, the benefits of CEA in this group are not certain among women). 10

The studies mentioned above emphasized the need for low perioperative complication rates if CEA benefits were to be realized. For example, for severe stenosis, the risk of ipsilateral stroke or death due to CEA was 5.8% and the risk of major stroke or death due to CEA was 2.5%. 6 For moderate symptomatic stenosis, the perioperative risk is almost the same: 6.7% for ipsilateral stroke or death, and 2.8% for major stroke or death. 6 On the other hand, to achieve benefits with CEA in patients with asymptomatic carotid artery disease, lower perioperative complication rates are required: 2.3% for ipsilateral stroke or death and 0.4% for death. 10

The American Heart Association and the National Stroke Association have established guidelines regarding the acceptable perioperative risks for CEA. The recommendations state that for symptomatic patients who undergo CEA, the acceptable risk of stroke or death as a perioperative complication is less than 6%, and for asymptomatic patients, the acceptable risk is less than 3%. 11,12 These guidelines have created substantial controversy in the surgical community because of the difference in the published vs actual perioperative risk of CEA seen in real-world practices. As noted earlier, the benefits of CEA increase as the degree of stenosis increases; thus, some surgeons more readily recommend endarterectomy for symptomatic patients with ≥70% stenosis than for patients with ≥50% stenosis. Similarly, some surgeons more readily recommend surgical revascularization for asymptomatic patients with ≥80% stenosis, than for patients with ≥60% stenosis. An understanding of each patient's perioperative risk and the individual surgeon's experience with CEA may influence the practice of recommending CEA or the referral patterns; for example, CEA may not be suitable for a patient with high perioperative risk unless the patient has a high benefit-risk ratio that may involve, for example, severe symptomatic stenosis. In any event, those patients are best served by highly experienced surgeons with acknowledged records of excellent procedural outcomes.
LIMITATIONS OF CEA

In spite of its demonstrated benefits, CEA has significant limitations. CEA has a high rate of perioperative complications, the first of these, ironically, is stroke. Complications related to general anesthesia also can be significant. Cardiovascular complications such as myocardial infarction (MI), congestive heart failure, and arrhythmias can occur, as can cranial nerve injury. Moreover, real-world complication rates may be higher than the rates seen in clinical trials. CEA studies such as NASCET and ACAS were undertaken at institutions that had reputations for demonstrated excellence. These studies used stringent inclusion and exclusion criteria, enrolled subjects who were low-risk patients, and included surgeons who are among the best. Thus, real-world complication rates for high-risk patients with relatively less experienced surgeons may be higher.

A retrospective national cohort study published in 1998 assessed real-world perioperative mortality among Medicare patients who underwent CEA in all nonfederal institutional settings. It included 113,300 Medicare patients who underwent CEA during 1992 and 1993 in trial hospitals (those participating in the NASCET and the ACAS studies) and in nontrial hospitals (all other nonfederal institutions performing CEA). Nontrial hospitals were considered in 3 groups that were based on volume of CEs performed. The researchers found differences among low-, medium-, and high-volume nontrial hospitals, and the trial hospitals. Low-volume hospitals had a 30-day mortality rate of 2.5%. Medium-volume hospitals had a 30-day mortality rate of 1.9%. High-volume hospitals had a 30-day mortality rate of 1.7%. The best outcome was seen in the trial hospitals—a 30-day mortality rate of 1.4%, which suggests that the surgeons in the trial hospitals and the trial hospitals. Low-volume hospitals had a 30-day mortality rate of 2.5%. Medium-volume hospitals had a 30-day mortality rate of 1.9%. High-volume hospitals had a 30-day mortality rate of 1.7%. The best outcome was seen in the trial hospitals—a 30-day mortality rate of 1.4%, which suggests that the surgeons in the trial hospitals were superior operators. Perioperative 30-day mortality rates in the trial hospitals during the studies were very low at 0.6% for NASCET patients and 0.4% for ACAS trial patients, which suggests that patients included in those clinical trials were lower-risk subjects.

Researchers concluded that real-world CEA mortality rates are significantly higher than those reported in clinical trials, and they advised that physicians use caution when translating the efficacy of carefully controlled studies of CEA to effectiveness in everyday practice. Thus, the benefits of CEA performed by less experienced operators or on relatively higher-risk patients may be substantially inferior to the benefits seen in clinical trials.13

Second, not every patient with carotid artery disease is a good candidate for CEA. Certain anatomic conditions can limit a patient's viability as a CEA candidate. High carotid bifurcation (above the second cervical vertebra) and intracranial stenosis are not easily accessible by surgery. Restenosis after CEA and contralateral occlusion may complicate the CEA procedure. For example, the risk of stroke or death after CEA in symptomatic patients more than doubles in the presence of contralateral occlusion (from 6.1% to 14.8%) in comparison to the same risk in those without contralateral occlusion. In asymptomatic carotid artery disease, the risk of stroke or death after CEA is almost 3 times higher in the presence of contralateral occlusion (increasing from 3.7% to 12.3%) compared to the absence of contralateral occlusion.13 Third, several medical conditions may complicate CEA and thus limit the eligibility of candidates for this procedure. These medical conditions include age >80 years, female sex, and comorbidities such as severe coronary artery disease, congestive heart failure, uncontrolled hypertension, severe peripheral vascular disease, chronic obstructive pulmonary disease, severe obesity, and uncontrolled diabetes mellitus.15,16

CAROTID STENTING

The leading alternative to CEA is carotid artery stent placement. The practice of stenting carotid arteries began more than 10 years ago, and the procedure has subsequently been refined.

BENEFITS OF STENT

Generally, revascularization of arterial stenosis with the use of stenting is less invasive than surgical techniques and has favorable periprocedural complication rates. CS is done in the catheterization laboratory under local anesthesia without the need for general anesthesia. Another advantage of CS is the relatively wide range of candidates with carotid artery stenosis who can be treated with this procedure. Appropriate criteria for candidacy for CS instead of CEA include high-carotid bifurcation, the presence of contralateral occlusion, restenosis after CEA, and patients with high perioperative risk related to comorbidities (Figure 2).

The largest single-center registry of data from carotid artery stent placements was published in 2001 by researchers who sought to determine short- and long-term outcomes among a large cohort of CS patients. The study included 528 patients (604 hemispheres/arteries) who underwent CS; of these, 13% were older than 80 years of age, 53% were women, and 15% had restenosis after CEA. At 30 days after the procedure, the minor nonfatal stroke rate was 5.5% of patients (4.8% of hemispheres) and the major nonfatal stroke rate was 1% of patients (1% of hemispheres). The fatal stroke rate was 0.3%, and the nonneurological death rate was 1%. Major nonfatal stroke and/or death was seen in 2.6% of patients (2.6% of hemispheres), and the rate for all nonfatal strokes and all deaths was 8.1% of patients (7.4% of hemispheres). The best predictor of 30-day stroke and death was age, with patients >80 years old being at lower risk.17 This study also assessed the long-term effects of stenting. After the 30-day period, the incidence of fatal and nonfatal stroke was 3.2%. Approximately 92% of
patients were free from ipsilateral or fatal stroke after 3 years. Interestingly, a changed outcome over time was seen in the study; during the 5-year study period, the 30-day minor stroke rate improved from 7.1% in the first year to 3.1% in the fifth year. This change underscores the value of experience in performing this procedure. The researchers concluded that CS can be performed with an acceptably low 30-day complication rate, and that the rate of fatal and nonfatal stroke after CS is relatively low over a longer follow-up period.\(^\text{17}\)

An account of real-world experience with CS was published in 2000 and included information from 36 centers throughout the world with a range of volume of operations. The source data comprised more than 5000 stenting procedures in patients considered to be at high risk for CEA. The technical success rate was 98.4%. The total numbers and rates of complications were as follows: 129 minor strokes or 2.72%, 71 major strokes or 1.49%, and 99 deaths or 1.9%. The combined rate of all strokes and deaths was 5.74%. Restenosis rates were 2% at 6-month follow-up and 3.5% after 12 months. The conclusions were that for CS, periprocedural risks for major and minor strokes and death are generally acceptable, and that stent is a viable alternative to surgery, especially for high-risk patients.\(^\text{18}\)

The Carotid and Vertebral Artery Transluminal Angioplasty Study (CAVATAS) was a randomized trial that sought to determine the risks and benefits of percutaneous transluminal angioplasty compared to CEA as treatments for carotid stenosis. In this multicenter clinical trial, 504 patients were randomized to CEA or angioplasty. For the latter group, stents were used selectively in 26% of patients only. The short- and long-term outcomes of ipsilateral stroke and ipsilateral stroke or death were nearly identical among the 2 groups. The researchers concluded that the major risks of angioplasty (with selective stent placement) as well as its effectiveness in preventing stroke for 3 years after the procedure were similar to those of CEA. Moreover, angioplasty had fewer minor complications, such as hematomas and cranial nerve injury, than did CEA.\(^\text{19}\)

**Embolic Protection Devices**

The major refinement to CS has been the introduction of devices that decrease the risk of stroke during the procedure. The main cause of procedural stroke is related to embolization of atherosclerotic material to the brain at the time of stenting. As a result, embolic protection devices have been developed to prevent or decrease the risk of distal embolization and subsequently decrease the risk of stroke during the CS procedure. Several devices can be used, but none of these are yet approved for CS; they are available for experimental protocols or for use in the revascularization of saphenous venous coronary bypass grafts.

The protection devices are either occlusive-aspiration or filtration systems. The GuardWire\(^*\) is an occlusion-aspiration thrombectomy device; it has a low-pressure distal occlusion balloon at the end of a wire that is positioned distal to stenosis. The wire functions as the angioplasty guide wire, and the distal balloon is inflated to occlude the distal vessel during CS to prevent atherosclerotic debris from embolization to the brain. After stenting, an aspiration catheter removes debris from the vessel by sucking the column of blood proximal to the inflated protection balloon. At the end of the procedure, the balloon is deflated and removed. The FilterWire\(^*\) is a filtration device that is positioned distal to the stenosis; atherosclerotic debris during CS is trapped by the filter, preventing embolization to the brain. The filter is then collapsed and removed.

The American Heart Association's 2002 conference included a presentation of the results of the SAPPHIRE trial (Stenting and Angioplasty with Protection in Patients at High Risk for Endarterectomy), a landmark clinical evaluation of the safety and efficacy of CS with protective devices. This was the first randomized study that compared CEA to CS with embolic protection in a group of high-risk patients, a category excluded from earlier trials. The study enrolled high-risk patients with asymptomatic carotid artery disease with at least 80% stenosis as well as those with symptomatic carotid artery disease and at least 50% stenosis. High risk was defined as age >60 years, presence of congestive heart failure, chronic obstructive pulmonary disease, previous CEA, previous neck radiation, or surgery and lesions distal or proximal to the bifurcation. Each patient was addressed by a multidisciplinary group of neurologists, interventionalists, and surgeons.
who all discussed the feasibility of CEA and CS. If it was agreed that CEA and CS were equally feasible, patients were randomized to surgery or stent revascularization. On the other hand, if the surgical team felt that CEA was not feasible, and the interventionalist felt that CS was feasible, the patient was enrolled in a stent registry group. Embolic protection devices were used in all stenting procedures, randomized or registry. Additionally, in a few cases in which the interventionalist felt stent was not feasible and the surgeon considered CEA feasible, patients were enrolled in a CEA registry group.

Nearly 99% of the patients were considered viable candidates for CS, but fewer than 50% were candidates for CEA, which confirms the position that CEA is not feasible for many carotid artery disease patients. There was no statistically significant difference in mortality at 30 days between the groups randomized to CEA or to CS: death occurred in 0.6% of the CS group and in 2% of the CEA group. Similarly, the risk of stroke at 30 days was similar in the 2 groups; stroke occurred in 5.3% of the CEA group and in 3.8% of the CS group. Nevertheless, the primary outcome of the study, which was the combined risk of death, MI, and stroke, was much higher in the CEA group compared to that same risk in the CS group (12.6% vs 5.8%, P=0.047). The stent registry had shown favorable results with a combined risk of death, MI, and stroke of 7.8%, which was close to the combined risk of 5.8% seen in the CS randomization arm, but much lower than the combined risks of 12.6% and 14.3% seen in the CEA randomization arm and the CEA registry, respectively. The SAPPHIRE trial demonstrated that CS with distal embolic protection is a viable alternative to, if not a better choice than, CEA in selected patients who are considered at high risk for perioperative morbidity and mortality (Table 2).

The ARCHer Trial (ACCULINK for Revascularization of Carotids in High-Risk Patients) was similar to the stent registry of the SAPPHIRE trial. It was a prospective, nonrandomized, multicenter, single-arm study that involved patients at 41 North American and South American centers. The 437 subjects were high-surgical-risk patients with at least 50% symptomatic stenosis or at least 80% asymptomatic stenosis, and with 1 or more of the high-risk factors mentioned above. Patients were implanted with the ACCULINK™ Carotid Stent System to treat atherosclerotic lesions in the internal carotid; in the latter phase of the study, patients were treated with ACCULINK in combination with the ACCUNET™ Embolic Protection System, a filter designed to trap particles of atherosclerotic plaque during the stenting procedure. The primary endpoint, 30-day risk of death, stroke, and MI, was 7.8%, which exactly reproduced the results of the SAPPHIRE stent registry. These findings confirmed the safety and acceptability of outcomes of CS with embolic protection in a high-risk patient population.

**LIMITATIONS OF CAROTID STENTING**

Several anatomic features can make CS perilous to undertake. Arterial access to the carotid artery may be problematic in patients with a tortuous aortic arch or severe peripheral arterial disease that has affected the femoral or iliac arteries. High-grade carotid stenosis and a tortuous cervical internal carotid artery may occasionally impair the deployment of a distal protection device. The short- and intermediate-term outcome data from the 5-year period following CS confirms that the majority of post-procedural complications occur soon after the procedure. Still, longer-term outcome data is warranted. Another important limitation on CS is that it is a highly specialized interventional procedure that should be performed only by a well-trained interventionalist.

**PROSPECTIVE INNOVATIONS IN CAROTID STENTING**

One potential refinement of CS involves the use of intravascular ultrasound (IVUS). The benefits and potential utility of IVUS during CS were addressed in a group of 54 consecutive CS procedures. Baseline and post-stent IVUS parameters were compared to quantitative carotid angiography data. Balloon and stent size selections were based on IVUS measurements. It was found that IVUS provided better information about stenoses and better data for selecting and sizing devices. Researchers concluded that IVUS during CS is safe, is useful for sizing devices, helps facilitate optimal stent deployment, and provides data that may favorably impact clinical outcomes; however, IVUS is costly, time-consuming, and its ultimate value in these procedures is, as yet, undetermined.

Another promising innovation in this area is the use of drug-eluting stents. Restenosis, which develops from a proliferation of tissue in the area of the stent

**Table 2. The SAPPHIRE Trial: 30-Day Outcomes**

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Stent* (n=156)</th>
<th>CEA† (n=151)</th>
<th>P</th>
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<tr>
<td>Death, %</td>
<td>0.6</td>
<td>2.0</td>
<td>0.36</td>
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<tr>
<td>Stroke, %</td>
<td>3.8</td>
<td>5.3</td>
<td>0.59</td>
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<td>Death and stroke</td>
<td>4.5</td>
<td>6.6</td>
<td>0.46</td>
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<tr>
<td>All MI, %</td>
<td>2.6</td>
<td>7.3</td>
<td>0.07</td>
</tr>
<tr>
<td>Death/stroke/MI, %</td>
<td>5.8</td>
<td>12.6</td>
<td>0.047</td>
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</table>

* Stent registry: 30-day death/stroke/MI = 7.8%.
†CEA registry: 30-day death/stroke/MI = 14.3%.
Data from Yadav JS, American Heart Association Scientific Sessions, 2002.
placement, is a major limitation of conventional stent procedures. The use of drug-eluting stents (rather than bare metal stents) decreases the incidence of restenosis after coronary artery stenting. Drug-eluting stents are not expected to have any effect on the acute outcomes of CS, but they may improve the durability of this procedure by decreasing the rate of restenosis.

**Future Treatment of Carotid Artery Disease**

Finally, the ultimate roles of CEA and CS for the treatment of carotid artery disease may yet be redefined by CREST (Carotid Revascularization Endarterectomy vs Stenting Trial; www.umdnj.edu/crestweb), sponsored by the US National Institute of Neurological Disorders and Stroke (NINDS) of the US National Institutes of Health (N I H). This is a prospective, randomized, multicenter clinical trial of CEA versus CS plus embolic protection devices as prevention measures for stroke. It will involve randomization to treatment of 2500 patients with symptomatic stenosis of ≥50%, and the results are expected in few years. The first primary outcome is death, stroke, and MI within 30 days; the second primary outcome is the long-term effect on ipsilateral stroke after 30 days up to 4 years. Secondary outcomes include sex differences, restenosis rates, subgroup analysis, quality and cost effectiveness, and a comparison of short- and long-term effects.23,24

**Conclusion**

CEA is a well-established surgical procedure for the treatment of symptomatic and asymptomatic carotid artery disease; however, CEA is not without limitations and the leading alternative to CEA is CS. Carotid stenting is an evolving and less invasive technique for carotid artery revascularization. Recent studies have demonstrated that CS with embolic protection devices is a viable alternative to CEA for high-surgical-risk patients and is the procedure of choice for stenoses that are inaccessible by surgery. The role of CS in low-risk patients awaits the completion of several ongoing studies.

Our approach to carotid artery revascularization is dynamic and reflects the rapid accumulation of data in this field. Currently, we prefer a multidisciplinary team of interventionalists, surgeons, and neurologists to provide a careful evaluation of the medical, CEA, and CS risks and then to recommend the best modality of revascularization. We define high-risk patients according to the criteria adopted by the SAPPHIRE and ARCHER trials mentioned above. Low-risk patients in whom CEA is feasible should undergo CEA or be referred for enrollment in ongoing trials when appropriate. High-risk patients in whom CS is feasible should be considered for CS. When CEA is not feasible and CS is feasible, patients should undergo CS. Embolic protection devices should be an integral part of all stenting procedures. Prudent decisions regarding the appropriateness of revascularization for all other kinds of patients should be made on an individual level.

**References**


