Implications of the Angiographic String Sign in Carotid Atherosclerosis

Ruth K. Fredericks, MD, T. Darrell Thomas, MD, David S. Lefkowitz, MD, and B. Todd Troost, MD

We identified 60 patients (42 men and 18 women with an average age of 62.6 years) with angiographically documented carotid stenoses of >95%; a string sign was demonstrated in 28. Twenty of the 60 patients (33%) were asymptomatic on presentation, 26 (43%) had hemispheric transient ischemic attacks, 21 (35%) had amaurosis fugax, and nine (15%) had previous ipsilateral infarctions. Demographics, mode of presentation, and prevalence of atherosclerotic risk factors were not significantly different between patients with and without a string sign. Doppler frequencies recorded in patients with a string sign were <6 or >16 KHz. Real-time ultrasonography imaged a patent lumen in all but three cases with a string sign. Surgery was performed in 26 patients with a string sign and in 21 patients without a string sign. The rate of major perioperative complications was not influenced by the presence of a string sign, contralateral extracranial stenosis, or ipsilateral siphon stenosis. Average lumen size of the endarterectomy specimens was 0.94 mm in those with and 1.7 mm in those without a string sign. We conclude that combined noninvasive testing has a sensitivity of 83% for demonstrating a residual lumen in patients with >95% carotid stenosis and that the angiographic string sign does not affect the mode of presentation or surgical outcome of these patients. (Stroke 1990;21:476-479)

A high-grade internal carotid artery (ICA) lesion associated with the angiographic appearance of a tapering, poststenotic segment of markedly reduced caliber (Figure 1) has been referred to as the slim sign,1 the string sign (SS),2 or atherosclerotic pseudo-occlusion.3 Collapse of the poststenotic lumen and layering of contrast in the dependent contrast in the dependent portion of the ICA are postulated to result from low blood flow.4 The use of delayed films, subtraction techniques, and the hanging head position during angiography may enhance the demonstration of a patent lumen.2,5 SS also occurs in nonatherosclerotic conditions.2,6-7 We retrospectively reviewed the records of 28 patients with an atherosclerotic SS and 32 patients with >95% ICA stenosis but no SS with respect to clinical presentation, atherosclerotic risk factors, noninvasive testing, angiographic findings, surgery, and long-term follow-up.

Subjects and Methods
The records of all cerebral arteriograms performed at the Bowman Gray School of Medicine during the past 10 years, beginning in January 1978, were retrospectively reviewed.

Demographic data, the presence of risk factors for atherosclerosis, medical history, and past treatment were derived from hospital records. Cranial computed tomograms (CCT scans) and angiographic films, both delayed and subtraction, were read by a neuroradiologist and one of the authors. Continuous-wave Doppler studies were performed using a Carolina Medical Electronics, Inc. DopScan (King, North Carolina) with a 5-MHz probe. Real-time ultrasonography was done with a Biosound 2000 Compact (Indianapolis, Indiana) using a 7.5-MHz transducer. Videotapes of the continuous-wave Doppler and real-time studies were reexamined. The results of gross examination of endarterectomy specimens were recorded from the pathology reports. Follow-up data was obtained by chart review and patient contact. Statistical analysis was performed using the Kruskal-Wallis analysis of variance by ranks.

Results
Twenty-eight patients had an angiographic SS associated with a high-grade ICA atherosclerotic stenosis. Thirty-two additional patients were identified with at least 95% cross-sectional stenosis of the ICA and poststenotic dilatation but no SS. Among those with an SS, the ICA contralateral to the SS demonstrated >95% stenosis in seven patients, 75-
FIGURE 1. Carotid arteriogram demonstrating long segment of poststenotic narrowing (arrows) consistent with string sign.

95% stenosis in three, and 50–75% stenosis in five. No patient had bilateral SSs. Among those without an SS, contralateral ICA stenosis of >95% was seen in five patients (75–95% stenosis in two and 50–75% stenosis in the other four). The incidence and degree of associated external carotid artery, bifurcation, and siphon stenosis did not differ significantly between the groups (Table 1). Mean±SD age was 61.1±10.3 years in the SS group and 64.0±9.2 years in the no SS group; 68% (19) of the patients with an SS and 72% (23) of the patients without an SS were men. Atherosclerotic risk factors were equally prevalent in the two groups. There was no significant difference in presenting symptoms and signs between the groups (Table 2).

Continuous-wave Doppler studies were performed on 42 patients (20 with an SS and 22 without) and real-time ultrasonography on 38 (18 with an SS and 20 without). Mean ICA Doppler frequency shifts were 9.0 KHz in 18 of the 20 SS patients in whom frequency shift was recorded and 12.4 KHz in those without an SS, but the difference between groups was not significant. The frequency shift in the region of the SS was bimodally distributed, with values of <6 or >16 KHz. Continuous-wave Doppler studies indicated vessel occlusion in six (30%) of the patients with and in only two (10%) of those without an SS, but the difference between groups was not significant. Simultaneous real-time studies identified patency of three vessels that were indicated to be occluded by continuous-wave Doppler sonography. The overall sensitivity of the combined studies was 83%. Reversal of ophthalmic artery blood flow did not distinguish between the groups.

CCT was performed in 20 patients at presentation. There were four CCT-documented infarcts in the patients without an SS and six in those with an SS; one of the six was subclinical.

Twenty-six patients with an SS and 21 without an SS underwent endarterectomy. In two patients with intracranial extension of the SS, failure to identify the upper extent of the lesion during surgery prevented completion of the endarterectomy. One ipsilateral perioperative infarction occurred in each group, both fatal. In the SS group, postendarterectomy hyperperfusion resulted in a large middle cerebral artery (MCA) hemorrhagic infarction on postoperative day 7. One patient without an SS suffered a nonhemorrhagic MCA infarction on postoperative day 20; this patient later died secondary to herniation. Pathologic specimens were available in 18 SS patients and 17 without an SS. Mean lumen diameter was smaller in the SS patients than in those without an SS, and no lumen was identified in two (11%).

<table>
<thead>
<tr>
<th>Table 1. Angiographic Data for 60 Patients With High-Grade Internal Carotid Artery Stenosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
</tr>
<tr>
<td>Location</td>
</tr>
<tr>
<td>Internal carotid artery</td>
</tr>
<tr>
<td>External carotid artery</td>
</tr>
<tr>
<td>Bifurcation</td>
</tr>
<tr>
<td>Siphon</td>
</tr>
</tbody>
</table>

% of n.
TABLE 2. Presenting Symptoms/Signs for 60 Patients With High-Grade Internal Carotid Artery Stenosis

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>With string sign (n=28)</th>
<th>With no string sign (n=32)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>%</td>
</tr>
<tr>
<td>Hemispheric ischemic attack</td>
<td>15</td>
<td>50%</td>
</tr>
<tr>
<td>Amaurosis fugax</td>
<td>12</td>
<td>43%</td>
</tr>
<tr>
<td>Infarction</td>
<td>5</td>
<td>18%</td>
</tr>
<tr>
<td>Asymptomatic</td>
<td>8</td>
<td>29%</td>
</tr>
<tr>
<td>Bruit</td>
<td>17</td>
<td>61%</td>
</tr>
</tbody>
</table>

However, no significant difference in lumen diameter was noted between the groups.

Long-term follow-up after endarterectomy was available in the 26 patients with an SS and in the 21 patients without, for means of 8.0 and 7.3 months, respectively. Two patients with and one patient without an SS developed symptomatic recurrent stenosis, two documented by angiography and the other by ultrasonography. One patient with an SS died of complications of a perioperative infarction >30 days after endarterectomy for contralateral asymptomatic stenosis.

**Discussion**

High-grade ICA stenoses usually appear as focal lesions <2 cm long with poststenotic dilatation. An elongated poststenotic wisps of contrast (referred to as an SS) may occur in several nonatherosclerotic conditions including dissection,2,4,7 radiation vasculopathy,8 and congenital hypoplasia.2,8 The SS should also be differentiated from signs of moyamoya disease,5 fibromuscular dysplasia,1 and technical pitfalls such as subintimal injection.9

Our series of patients with atherosclerotic SSs is the largest reported to date. We found no difference in demographics, presentation, or the prevalence of atherosclerotic risk factors between patients with SS and other patients with highly stenotic ICA lesions. Roughly one third of the patients in each group were asymptomatic, and two thirds had bruits; <20% in each group had documented infarcts at the time of presentation. One SS patient had a subclinical ipsilateral infarct on CCT.

The role of noninvasive testing in imaging the SS is controversial.5,10 Our experience has been that mean Doppler frequency shifts in the MCA proximal to an SS are similar to those in arteries without an SS. Continuous-wave Doppler studies were inappropriately interpreted as demonstrating occlusion in six patients with an SS (30%) but in only two patients without an SS (10%). The frequency shift within the SS lesion itself was <6 or >16 KHz, indicating either low blood flow or a jet-like high-velocity state. Doppler shifts at the site of stenoses without SSs ranged from 9 to 16 KHz. The role of real-time ultrasonography in the evaluation of SS lesions has not been previously reported. In our patients, real-time ultrasonography had a sensitivity of 83% and documented patency in three arteries that were indicated to be occluded by continuous-wave Doppler studies. Reversed blood flow in the ophthalmic artery did not consistently predict high-grade stenosis in either group. Arteriography was required to prove patency in the remaining 17% of SS lesions. Previous studies have demonstrated that noninvasive testing may not reliably differentiate ICA occlusion from high-grade ICA stenosis.11-13 Therefore, if noninvasive testing is consistent with occlusion, the clinician should consider angiography to demonstrate a residual lumen in patients who are otherwise candidates for surgery.

The natural history of unoperated carotid artery lesions exhibiting an angiographic SS is poorly characterized. Despite assertions that the SS represents an unstable, preocclusive lesion mandating emergency surgery,3 recommendations for surgical management are based on anecdotal data.1,3-5 It is unclear how frequently SS lesions progress to occlusion. Gabrielsen et al8 described a patient with pseudo-occlusion whose artery remained patent without surgery over 5 years of follow-up. Furthermore, the natural history of ICA occlusion remains controversial.14-17

Angiography did not adequately visualize the intracranial extension of the SS lesion in two patients; however, the groups with and without an SS had similar perioperative mortality and infarction rates. One patient in each group died of a massive postoperative stroke. Pathologic examination did not reveal significant differences between the groups in lumen size nor did it enhance the characterization of lesion type. Long-term follow-up after endarterectomy of up to 30 months was available in 47 patients. Mean follow-up was 8 months in the 26 patients with an SS and 7.3 months in the 21 patients without an SS; <10% of the patients in each group had recurrent symptoms.

In conclusion, the clinical presentation and outcome of patients with carotid stenosis associated with the angiographic SS do not differ significantly from those with high-grade carotid lesions and no SS. Ultrasonography was 83% sensitive in demonstrating a residual lumen when an SS was present, and real-time imaging was superior to Doppler. In 17% of the patients, combined noninvasive testing failed to demonstrate a patent lumen. Therefore, arteriography should be considered when ultrasonography shows no occlusion. Angiography was not always able to demonstrate the upper extent of the SS lesion, but poor visualization of the intracranial vasculature did not influence the perioperative or postoperative outcome in the SS group. SS lesions may be managed surgically without a significant increase in the complication rate.

Note added in proof. Since submission of our manuscript, O'Leary et al10 have reported their experience with surgical and medical management in 34 patients with ICA pseudo-occlusion.
References

Key Words • carotid artery diseases • endarterectomy • ultrasonics
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