Transcranial Doppler Monitoring of Transcervical Carotid Stenting With Flow Reversal Protection
A Novel Carotid Revascularization Technique

Marc Ribo, MD, PhD; Carlos A. Molina, MD, PhD; Beatriz Alvarez, MD, PhD; Marta Rubiera, MD; Jose Alvarez-Sabin, MD, PhD; Manel Matas, MD

Background and Purpose—Transfemoral carotid stenting, despite becoming very frequent, has some limitations such as difficult groin access in few patients, lack of distal protection during filter placement, or embolization despite protection. Transcervical stenting (TCS) is a novel technique during which a common carotid to jugular vein shunt is placed creating a protective reversal flow in the internal carotid artery after proximal common carotid artery (CCA) clamping. We aim to study, with transcranial Doppler (TCD), cerebral flow changes and microemboli detection during transcervical stenting.

Methods—From September 2005 to March 2006, of 65 consecutive patients eligible for carotid revascularization, 23 were considered high risk (sapphire criteria) and underwent TCS. Neurologic examination was performed before and after the procedure by a neurologist and a preprocedure vascular reactivity TCD examination was done in all patients.

Results—After CCA clamping, flow inversion was observed in the anterior cerebral artery, supplying blood to the middle cerebral artery (MCA) and internal carotid artery (reversal). TCD did not detect any air/solid emboli during stent deployment and angioplasty confirming the reversal flow protection hypothesis. Mean reversal flow time was 15.4 minutes; in all cases, substantial MCA flow was present during CCA clamping (initial mean velocity 30 cm/s), and a slow gradual increase was observed traducing collateral flow recruitment (mean velocity after 5 minutes 36 cm/s, \(P<0.001\)). Flow increase was observed in all patients except in those with preprocedural exhausted ipsilateral vascular reactivity (16% versus 2%, \(P=0.036\)). The only in-procedure complication was one transient ischemic attack. After CCA unclamping, normal antegrade flow was restored in anterior cerebral artery and mean final MCA velocity increased 16% according to preprocedure flow.

Conclusions—TCS with protective internal carotid artery flow reversal can eliminate showers of micoremboli during stent deployment making it a promising carotid revascularization technique in high-risk patients with carotid stenosis. (Stroke. 2006;37:2846-2849.)

Key Words: carotid artery ■ carotid stenosis ■ stenting ■ TCD

In the last few years, transfemoral carotid artery stenting (CAS) has emerged as a potential alternative to endarterectomy in terms of both safety and efficacy. The results of the SAPPHIRE trial\(^1\) led to approval of CAS devices by the US Food and Drug Administration and an important widespread use of this technique worldwide. The trial proved that among high-risk patients with severe carotid artery stenosis and coexisting conditions, CAS with the use of an emboli protection device is not inferior to carotid endarterectomy. Despite its relative good results, in the periprocedural period, the cumulative incidence of stroke, myocardial infarction, or death was 4.8% among patients assigned to receive a stent. The main hazard of CAS is that atherosclerotic material dislodged during the procedure may embolize to the cerebral circulation resulting in cerebral ischemia. Cerebral filtering devices reduce thromboembolic complications during CAS\(^2,3\); however, the degree of protection appears to be incomplete.

Transcervical carotid stenting (TCS) is a novel technique during which, after a small incision in the neck, a shunt from the common carotid artery (CCA) to the jugular vein is placed.\(^4\) After proximal CCA clamping, a protective reversal flow in the stenosed internal carotid (ICA) is created. Reversal flow aims to avoid cerebral embolization during stent deployment and angioplasty. We aimed to study, with transcranial Doppler (TCD), cerebral flow changes and distal embolization during TCS.

Methods—From September 2005 to February 2006, carotid revascularization was indicated in 65 patients in our institution; all patients considered...
high risk according to SAPPHIRE criteria\(^1\) underwent TCS with carotid flow reversal. At least one of the following criteria for high risk was required: clinically significant cardiac disease, severe pulmonary disease, contralateral carotid occlusion, contralateral laryngeal nerve palsy, previous radical neck surgery or radiation therapy to the neck, recurrent stenosis after endarterectomy, or age >80 years. Patients with proximal CCA stenosis were excluded.

Complete neuroexamination was performed in all patients before and after the procedure by a stroke neurologist who was also present during the surgical procedure to assess intraoperative neurologic symptoms. The study was approved by the institutional ethics committee.

**Surgical Technique**

All patients receive antiplatelet agents before the procedure, there is no need for preoperative arteriography, and the procedure can be planned solely on the basis of duplex ultrasound.

The technique of TCS with carotid flow reversal was described elsewhere\(^4,6\) (Figure 1). Briefly, the procedure is done with the patient under local anesthesia with selective use of intravenous sedation. A 3- to 4-cm vertical incision is placed between the clavicular and sternal heads of the sternocleidomastoid muscle. The CCA is dissected in a length of approximately 1.5 cm just cephalad to the superior edge of the clavicle and encircled with a rubber-band loop. The ipsilateral internal jugular vein is percutaneously punctured under direct visualization and an introducer sheath placed in a cardiac direction. An introducer sheath is then advanced into the CCA in a cranial direction ensuring that only 3 cm is advanced into the CCA. The venous and arterial sheaths are then connected and the fistula connections opened to ascertain an arterial–venous shunt. The CCA is occluded by tightening the rubber-band loop or by external clamping. The newly created pressure gradient inverts flow in both the internal and external carotid territories toward the shunting system and the jugular vein. A digital subtraction angiogram allows visualization of contrast washing into the venous end of the fistula simultaneously identifying the A1 segment of the ipsilateral anterior cerebral artery (ACA) or terminal intracranial ICA. Several TCD parameters were recorded: initial MCA mean velocity, ACA/terminal ICA flow inversion after CCA occlusion, mean MCA velocity during CCA occlusion, microemboli shower detection during the different steps of the procedure, and final mean MCA velocity.

**Transcranial Doppler Protocol**

Before the surgical procedure, all patients underwent a complete TCD examination (power-mode Doppler, Spencer Technologies PMD-100) to assess intracranial flow status, the presence of concomitant intracranial stenosis,\(^7\) and bilateral cerebral vascular reactivity (breathing test).\(^8\) During the whole procedure, we monitored with TCD cerebral flow status and microemboli using the automatic emboli detection function. A head frame allowed ultrasound probe fixation and continuous flow assessment in M1 segment of the middle cerebral artery (MCA). When possible, sonographers confirmed under direct visualization and an introducer sheath placed in a cranial direction ensuring that only 3 cm is advanced into the CCA. The venous and arterial sheaths are then connected and the fistula connections opened to ascertain an arterial–venous shunt. The CCA is occluded by tightening the rubber-band loop or by external clamping. The newly created pressure gradient inverts flow in both the internal and external carotid territories toward the shunting system and the jugular vein. A digital subtraction angiogram allows visualization of contrast washing into the venous end of the fistula confirming flow reversal in the carotid. Under fluoroscopic guidance and after predilation if needed, the stent is deployed over the stenosis and balloon angioplasty is performed. Once the final arteriography is satisfactory, 10 to 20 mL of blood is vigorously aspirated through a syringe to remove potential debris before reestablishing antegrade flow in the ICA.

**Results**

Twenty-three patients fulfilled the high-risk criteria and therefore underwent TCS with reversal carotid flow. Mean age was 79 years and 10 patients (43.4%) had a symptomatic carotid lesion. Four patients (17.4%) presented an exhausted cerebral vascular reactivity before stenting; other demographic characteristics are shown in Table. Insufficient temporal bone window precluded TCD monitoring in one patient.

After CCA clamping, flow inversion was observed in the ACA or terminal ICA (Figure 2) supplying blood to the MCA and ICA (reversal). TCD did not detect any air/solid emboli during the CCA clamping time (n=22; 0%), confirming the reversal flow protection hypothesis. Single isolated emboli signals were observed during CCA puncture and a short shower at CCA declamping.

Mean reversal flow time was 15 minutes; in all cases, substantial MCA flow was present during CCA occlusion (initial mean velocity 30.1 cm/s). A slow gradual increase was observed in the following minutes traducing collateral flow recruitment (mean velocity after 5 minutes 36 cm/s, \(P<0.001\)). Flow increase was observed in all patients except in those with preprocedural exhausted ipsilateral vascular reactivity (16% versus 2%, \(P=0.036\)). Most patients remained awake during the procedure; occasionally, conscious sedation was needed. No neurologic deficits were observed during the procedure related to flow decrease after clamping. After CCA unclamping, normal antegrade flow was restored in the ICA. The only in-procedure complication was one transient ischemic attack (lasting 30 minutes in the ipsilateral

**Demographic Characteristics of the Study Population**

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>74.5</td>
<td>(7.8)</td>
</tr>
<tr>
<td>Gender (female)</td>
<td>21.7%</td>
<td>(n=5)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>87%</td>
<td>(n=19)</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>30.4%</td>
<td>(n=7)</td>
</tr>
<tr>
<td>Tobacco</td>
<td>17.4%</td>
<td>(n=4)</td>
</tr>
<tr>
<td>Dyslipidemia</td>
<td>52.2%</td>
<td>(n=11)</td>
</tr>
<tr>
<td>Ischemic cardiopathy</td>
<td>56.5%</td>
<td>(n=12)</td>
</tr>
<tr>
<td>Contralateral &gt;50% ICA stenosis</td>
<td>39.1%</td>
<td>(n=11)</td>
</tr>
<tr>
<td>Symptomatic lesion</td>
<td>43.5%</td>
<td>(n=10)</td>
</tr>
<tr>
<td>Tandem ipsilateral intracranial lesion</td>
<td>30.4%</td>
<td>(n=7)</td>
</tr>
<tr>
<td>CCA occlusion time (minutes)</td>
<td>14.3</td>
<td>(5.5)</td>
</tr>
<tr>
<td>Initial mean MCA flow velocity (cm/s)</td>
<td>47</td>
<td>(25.6)</td>
</tr>
<tr>
<td>Final mean MCA flow velocity (cm/s)</td>
<td>55</td>
<td>(29.6)</td>
</tr>
</tbody>
</table>

*Percent (n) or mean (SD).
ACA territory) discovered at the end of surgery, after CCA unclamping. Overall, ipsilateral cerebral flow improved after stenting; mean final MCA velocity increased 17% according to preprocedure flow (initial mean velocity 47; final 55 cm/s, \( P = 0.008 \)).

Discussion

Our study demonstrates that TCS with reversal carotid flow is an effective carotid revascularization technique that effectively protects from cerebral embolization during the procedure. In previous reports, Criado et al demonstrated that TCS is feasible and safe\(^9\); however, theoretical protection offered by reversing carotid flow was not conclusively demonstrated. By continuously monitoring cerebral flow, TCD not only directly assures flow reversal in the terminal ICA, but detects also microembolization or other flow disturbances. This information is extremely valuable in the operating room and gives confidence to the surgeon.

The efficacy of cerebral protection devices (CPD) in preventing cerebral emboli has not been proven; some authors even advocate that stent placement yields more microemboli in patients treated with filtering CPDs than in unprotected procedures.\(^10\) Nevertheless, current consensus makes cerebral protection during transfemoral carotid angioplasty advisable. CPDs provide protection by capturing large numbers of particulate debris during the intervention. Unfortunately, even if considered 100% efficient, these systems allow embolization during initial crossing of the carotid lesion, especially in those cases in which unprotected previous angioplasty is needed to cross the tight stenosis with CPD. Finally, even if rarely, CPDs may produce carotid intimal injury,\(^11\) dissection, or spasm during deployment and may release emboli during retrieval.

Flow reversal during TCS as a protective measure was ideated by Parodi\(^12\) to overcome conventional CPD limitations. Reversal of flow in the ICA is obtained occluding the CCA with a balloon catheter and creating an arteriovenous fistula with the femoral vein while the external carotid artery is occluded with a second balloon. This technique has been shown to reduce embolic signals detected by TCD.\(^13\) However, the length and caliber of the protection catheter produces a high resistance that limits the arteriovenous gradient and therefore hampers the reversal flow. Other potential complications of the transfemoral approach include embolization from the aortic arch, supraaortic trunk instrumentation, and technical difficulty resulting from tortuous supraaortic trunks or occlusive disease of aorticiac or femoral arteries.

Our technique provides cerebral protection by reversing flow in the internal and external carotid arteries before crossing the stenosis, avoiding complications of the transfemoral approach. TCD provides real-time monitoring, detecting hypoperfusion, embolism, or thrombosis during surgical and stenting carotid procedures. Information obtained with TCD such as microemboli showers after stent deployment or persistent reduction of MCA flow velocities are independently associated with cerebral deficits.\(^14\) Other studies point to the link between MCA flow velocity and likelihood of decreased clearance of cerebral emboli during stenting.\(^15\) In our study, the use of TCD confirmed the absence of embolic signals during stent deployment proving the protective properties of reversal flow. TCD also assesses real-time cerebral blood flow during stenting; after an initial drop after CCA occlusion, a slow gradual velocity increase is observed in MCA traducing collateral flow recruitment. Interestingly, those patients with preexisting exhausted ipsilateral vascular reactivity could not efficiently compensate the flow after CCA occlusion. Using TCD, any flow disturbance such as severe hypoperfusion after angioplasty-induced hypotension can immediately be depicted, and appropriate measures can be rapidly taken.

Short clusters of microemboli were detected at declamping. Clamping is performed at a lower level of the CCA where the artery wall is usually clean, without plaques (as previously confirmed in every case by ultrasound and magnetic resonance angiography). The observed emboli at declamping are therefore most likely gaseous and lacking in clinical significance.

Conclusions

TCS with protective ICA flow reversal can eliminate showers of microemboli during stent deployment making it a promising carotid revascularization technique in high-risk patients with carotid stenosis.

Disclosures

None.
References


Transcranial Doppler Monitoring of Transcervical Carotid Stenting With Flow Reversal Protection: A Novel Carotid Revascularization Technique
Marc Ribo, Carlos A. Molina, Beatriz Alvarez, Marta Rubiera, Jose Alvarez-Sabin and Manel Matas

Stroke. 2006;37:2846-2849; originally published online September 28, 2006;
doi: 10.1161/01.STR.0000244781.68371.59
Stroke is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2006 American Heart Association, Inc. All rights reserved.
Print ISSN: 0039-2499. Online ISSN: 1524-4628

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://stroke.ahajournals.org/content/37/11/2846

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Stroke can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Stroke is online at:
http://stroke.ahajournals.org//subscriptions/