Patency of External and Internal Carotid Artery in the Presence of an Occluded Common Carotid Artery: Noninvasive Evaluation With Combined Cerebrovascular Doppler Examination and Sequential Computertomography

Herbert M. Keller, M.D., Ph.D., Anton Valavanis, M.D.,* Hans-Georg Imhof, M.D.,† and Marco Turina, M.D.‡

SUMMARY The patency of the external carotid artery (ECA) and internal carotid artery (ICA) in the presence of an occlusion of the common carotid artery (CCA) was evaluated in 7 patients with a symptomatic CCA occlusion by the combined application of cerebrovascular Doppler examination (cv-Doppler) based on continuous-wave equipment and sequential computertomographic scans with intravenous bolus injection of contrast material (sequential CT-scans). Occlusion of the CCA was demonstrated by cv-Doppler and sequential CT-scans and confirmed by routine angiography. A patent ECA was found in all 7 patients by the combined method, but could not be demonstrated by routine angiography in one of these patients. A patent ICA was found in 2 patients by the combined method, while routine angiographic findings concerning the patency of the ICA were equivocal. An occluded ICA was found in 5 patients by the cv-Doppler-sequential CT-scans method, where routine angiographic findings also were equivocal. Operation to restore blood flow in the CCA was performed in 5 patients and successful in 3 patients in whom blood flow from the CCA to the ECA could be achieved in 2 patients, and to the ECA and ICA in one patient, as predicted by the combined cv-Doppler-sequential CT-scans method. Thus, the patency of the ICA in the presence of a CCA occlusion can be reliably evaluated by the combined diagnostic procedure. The method may help to decide for further diagnostic work-up, e.g., specific selective injections and projections in more than two plans during cerebral angiography, and/or successful surgical intervention in a given patient with a CCA occlusion, even if angiographic findings are equivocal.

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STENOSES AND OCCLUSIONS of the common carotid arteries (CCA) are less frequent than obstructions in the internal carotid arteries (ICA).1-3 Atherosclerosis is the most common cause of these lesions, while fibromuscular dysplasia, collagen tissue disease with arteritis, postradiation fibrosis, and blunt or open cranio cervical trauma are rare.3-2 Furthermore, backwards thrombosis from a lesion in the ICA may cause a CCA obstruction.3 4 The external carotid artery (ECA) can remain patent in the presence of a CCA occlusion, since many collaterals between branches of the ECA and other extracranial arteries exist, e.g. the thyroid arterial network, vertebral to ECA anastomoses, and arteries arising from the thyrocervical and costocervical trunk.8 9 Thus, retrograde collateral blood flow in the proximal segment of the ECA can occur and keep the ICA patent as demonstrated in 14 of 22 patients in the operative series of Wylie and Effeny, and in 6 of 7 patients in the operative series of Podore and coworkers.3 8 10 Routine selective angiography of the extracranial cerebral arteries will demonstrate a CCA occlusion and usually its level, as well as collateral blood flow to the ECA in most cases.9 The patency of the ICA, however, may not be seen, especially in those cases with only minimal collateral blood flow to a still patent ICA.9 10 The question arises whether surgical exploration of the carotid bifurcation alone can prove patency or chronic occlusion of the ICA in the presence of a CCA occlusion, as proposed by Podore and coworkers.10

In this paper a combined noninvasive diagnostic procedure with cerebrovascular Doppler examination based on continuous-wave equipment (cv-Doppler) and sequential computertomographic scans at different levels of the neck with intravenous bolus injection of contrast material (sequential CT-scans) is presented.11-14 15-17 The purpose of the paper is to demonstrate that the combined application of these two noninvasive methods will not only show an obstruction in the CCA, but also the collateral blood flow to the ECA, the natural anastomoses used to bypass the obstruction and the patency of the ECA and ICA.

Method

CV-Doppler examination based on continuous-wave equipment is a well established diagnostic tool to evaluate the patency of the carotid artery, the central portion of the subclavian artery, the vertebral artery (VA) and the natural collateral arterial pathways used to bypass a severe obstruction in one or several aortocranial arteries.11-14 Imaging Doppler systems and echo-B-mode ultrasound systems with or without Doppler analysis (Duplex systems) can be used additionally to visualize carotid lesions, but are not neces-
Collateral reserve of the extracranial vascular system may influence the decision for further diagnostic work-up and treatment. The indirect criteria are evaluated by recording blood flow signals from the terminal branches of the ophthalmic arteries in the supraorbital region with and without digital compression of branches of the ECA and the CCA ipsi- and contralaterally. The direct criteria are evaluated by percutaneous and retrotonsillar recording of blood flow signals and its frequency spectrum directly from the CCA, ICA, and ECA with the ear used as a natural frequency analyser. Additional manoeuvres such as rhythmic digital compression of ECA branches, pressing the tongue against the palatum, or swallowing are used to differentiate and identify respectively the CCA, ICA and branches of the ECA. Thus, major ulcerated lesions, stenoses and occlusions in the CCA, ECA and extracranial portion of the ICA can be detected with high reliability, i.e. these lesions can be localized in many cases, quantified and qualified, and collateral arterial pathways identified. Collateral pathways in the presence of a CCA occlusion can be further identified by oscillation manoeuvres (fig. 1). Hereby, oscillations are generated by digitally tapping the VA in the region of the atlas loop and propagate to the ECA, if VA-ECA anastomoses are in collateral function. Oscillations generated in branches of the contralateral ECA or arteries arising from the thyrocervical or costocervical trunk propagate to the ECA, if these arteries are in collateral function. Furthermore, these oscillations can be registered in the proximal segment of the ICA, if blood flow from these collaterals reaches a still patent ICA.

Information on the patency of the subclavian and vertebral arteries is necessary in a given patient with CCA occlusion or multiple carotid lesions, since the
1. A patent ECA was found in all 7 patients by the combined noninvasive method but could not be demonstrated by routine angiography in one of these patients. A patent ICA was found in 2 patients by the combined method, where routine angiographic findings concerning the patency of the ICA were equivocal. An occluded ICA was found in 5 patients by the cv-Doppler-sequential CT-scans method, where routine angiographic findings also were equivocal.

Thrombendarterectomy of the CCA was performed in 5 patients and successful in 3 patients in whom blood flow from the CCA to the ECA could be achieved in 2 patients, and to the ECA and ICA in one patient, as predicted by the combined cv-Doppler-sequential CT-scans method. Of these, one patient with suspected backwards thrombosis after ICA endarterectomy did not have angiography, but underwent reconstructive surgery immediately after diagnosis. Thus, the validity of the noninvasive combined method was confirmed by operation alone. One patient with a fibrotic CCA occlusion and another patient with a patent ICA and ECA on the side of the occluded CCA had endarterectomy of the asymptomatic contralateral high-grade lesion in either the ICA or both, the ICA and the brachiocephalic trunk. These operations were performed to improve collateral blood flow to the side of the occluded CCA. Another patient had no operation because collateral blood flow was considered to be sufficient to bypass the occluded CCA, and the cerebrovascular episodes had ceased for more than 2 months during medical treatment. Thus, the results of the combined cv-Doppler-sequential CT-scans were confirmed in all 5 patients who underwent surgery for the occluded CCA.

**Typical Patient Reports**

The following two patient reports, one with and one without a patent ICA in the presence of an occluded CCA are used to demonstrate the typical findings of the combined cv-Doppler-sequential CT-scans method.

**Case 1 (patient B.P. in table 1, figure 2)**

A 37 year old male patient suffered a penetrating traumatic neck lesion on the left side. Emergency surgery for muscle, jugular vein, and recurrent nerve
lesions was performed within a few hours after the accident. Hypaesthesia on the ulnar side combined with weakness of the left hand were complained a few days later. Therefore, an additional lesion of the brachial plexus was suspected and electromyography was performed within a few hours after the accident. A permanent visual upper field defect in the right eye with sudden onset after several episodes of amaurosis fugax and a TIA with paresis of the right arm and leg occurred in a 53 year old male patient who had X-ray treatment for a carcinoma on the right side of the neck 25 years before admission. Neurological examination was normal, but the right common carotid artery and the right temporal superficial artery were not palpable. CV-Doppler examination indicated an occlu-

<table>
<thead>
<tr>
<th>Table 1 (Continued)</th>
<th>Consecutive CT-slices of the neck</th>
<th>Cerebral angiography</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>occlusion of right CCA, ICA, and proximal ECA</td>
<td>proximal occlusion of right CCA, filling of branches of right ECA through VA-ECA anastomosis, missing right ICA</td>
<td>not done</td>
<td></td>
</tr>
<tr>
<td>occlusion of left CCA, patent left ECA and ICA</td>
<td>proximal occlusion of left CCA filling of branches of the left ECA through VA-ECA anastomoses, probably patent left ICA with weak flow</td>
<td>successfully performed endarterectomy on left CCA with restored blood flow from CCA to ECA and ICA</td>
<td></td>
</tr>
<tr>
<td>—occlusion of left CCA, patent left ECA and ICA with calcifications</td>
<td>intrathoracic occlusion of left CCA, minor filling of left ECA and ICA via anastomoses from the vertebral and/or thyroidal arteries (not detectable precisely on angiograms)</td>
<td>not performed on left CCA, but endarterectomy on right ICA and brachiocephalic trunk</td>
<td></td>
</tr>
<tr>
<td>—calcified stenosis of right ICA</td>
<td>high grade stenosis of right ICA, moderate stenosis of brachiocephalic trunk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>occlusion of right CCA and ICA, patent right ECA</td>
<td>occlusion of right CCA 2 cm proximal of carotid bifurcation, patent right ECA filled from VA, no filling of right ICA</td>
<td>thrombendarterectomy of right CCA successfully, of right ICA not successfully performed</td>
<td></td>
</tr>
<tr>
<td>occlusion of left CCA and ICA, patent ECA</td>
<td>—occlusion of left CCA 4 cm distal to aortic arch, collateral filling of left ECA from VA</td>
<td></td>
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</tr>
<tr>
<td>—high grade stenosis of distal right CCA and proximal ICA with collateral filling of arteries of left hemisphere through ACA</td>
<td>—high grade stenosis of right ICA, moderate stenosis of brachiocephalic trunk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>occlusion of left CCA, patent left ECA, occluded left ICA</td>
<td>proximal occlusion of left CCA, left ECA and ICA not shown on angiogram</td>
<td>—operative exploration of left CCA, recanalization not possible</td>
<td></td>
</tr>
<tr>
<td>—operative exploration of left CCA, recanalization not possible</td>
<td></td>
<td></td>
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<tr>
<td>—in the same session fourfold aorto-coronary bypass surgery performed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>occlusion of left CCA and ICA, patent left ECA</td>
<td>not done</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>thrombotic occlusion of left CCA and ICA (backwards thrombosis?), thrombendarterectomy of left CCA and ECA successfully, of left ICA not successfully performed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The CCA were seen in the form of a ring-like enhancement. At the level of the fourth cervical vertebra, however, patent left ICA and ECA were found on both sides, i.e. the contrast bolus passed through these arteries, but was delayed on the side of the CCA occlusion. An occluded left CCA and collateral blood flow from the left VA to the left ECA through muscular branches of the VA was demonstrated angiographically. Angiography was equivocal as concerning the patency of the ICA. Surgery was performed on the left CCA and an intimal flap with consecutive thrombosis was found. Blood flow from the left CCA to the left ECA and ICA was restored. CV-Doppler findings were normal after the operation.

Case 2 (patient A.A. in table 1, figure 3)

A permanent visual upper field defect in the right eye with sudden onset after several episodes of amaurosis fugax and a TIA with paresis of the right arm and leg occurred in a 53 year old male patient who had X-ray treatment for a carcinoma on the right side of the neck 25 years before admission. Neurological examination was normal, but the right common carotid artery and the right temporal superficial artery were not palpable. CV-Doppler examination indicated an occlu-
Results of cv-Doppler, sequential CT-scans, and angiography in a 37 year old patient with a CCA occlusion and a patent ECA and ICA after a traumatic neck lesion on the left side (patient B.P. in table 1). (a) cv-Doppler findings: Direct and indirect Doppler findings of the left carotid artery were pathological and are depicted in the middle portion of the figure. Blood flow signals from the left supratrochlear artery were normal in direction, but weaker on the right side. An increase of flow signals occurred when the right temporal superficial artery (2) was compressed. And, a minor decrease of signals was registered, when the right CCA (6), or the right or left facial artery (3) were compressed digitally. Blood flow signals from the left supraorbital artery were also normal in direction and weaker than on the right side. An increase of flow was observed when the right temporal superficial artery was compressed digitally (2). Flow signals from the left temporal superficial artery were very weak. The left ECA and ICA could be identified in the region of the carotid bifurcation. The former had normal blood flow signals, and signals from the latter were weak. No signals could be picked up from the left CCA. Oscillations generated in the atlas portion of the left VA could be registered from the left ECA (see figure 1J). Furthermore, the left VA showed higher blood flow signals in comparison to the right VA. Doppler findings after thrombendarterectomy of the left CCA with restoration of blood flow to the left ECA and ICA were normal and are depicted on the right side of the figure. Abbreviations: AST = A.supratrochlearis, ASO = A.supraorbitalis, ATS = A.temporalis superficialis, c = digital compression phase, v = velocity (flow) signals, t = time, 1–6 = digital compression manoeuvres performed on branches of the ECA and the CCA, even numbers for right side, odd numbers for left side. (b) Angiographic and sequential CT-scans findings: Selective angiography of the left CCA (lower angiogram) demonstrated an occlusion (marked by an arrow). Filling of branches of the left ECA through muscular branches of the left VA was demonstrated and contrast material reached a probably patent left ICA, but the findings were equivocal. Sequential CT-scans at the level of the sixth cervical vertebra (CT-slice at C6) with intravenous Telebrix®-injection showed a patent CCA on the right side, and a ring type enhancement of the vaso vasorum of the left CCA. CT-scans at the level of the fourth cervical vertebra (CT-slice at C4) demonstrated a patent left ECA and ICA, i.e. passage of contrast material was seen in these two arteries, but was delayed as compared to the right side.
A vert

Figure 3. Results of cv-Doppler, sequential CT-scans, and angiography in a 53 year old patient with a patent ECA and a chronic occlusion of the CCA and ICA on the right side after X-ray treatment of a tumour in the region of the right neck (patient A.A. in table 1). (a) cv-Doppler findings: Direct and indirect Doppler findings of the right carotid artery were pathological and are depicted in the left portion of the figure. Blood flow signals from the right supratrochlear artery were reverse, i.e. from extra- to intracranial, and a decrease of flow occurred when the left temporal superficial artery (1), left facial artery (3), or left CCA (5) were compressed digitally. Blood flow signals from the right supraorbital artery were normal in direction, but weaker than those on the left side, and no increase of flow occurred, when the right temporal superficial artery was compressed digitally (2). Blood flows signals from the right ECA were weaker than those on the left side, and oscillations generated in the atlas portion of the right VA were superimposed on the ECA blood flow signals. No flow signals could be detected over the right CCA and ICA. (for abbreviations see figure 3, reverse flow direction is below baseline).

(b) Angiographic and sequential CT-scans findings: Angiography of the aortic arch (lower angiogram) showed an occlusion of the right CCA in its proximal portion (marked by an arrow). Selective angiography of the right VA demonstrated filling of branches of the right ECA through muscular branches of the VA (marked by the arrow in the upper angiogram). No contrast material was detected at the usual location of the right carotid bifurcation. Sequential CT-scans at the level of the fifth cervical vertebra (CT-slice at C5) with intravenous Telebrix®-injection showed a patent CCA on the left side, and enhancement of the vasa vasorum of the right CCA. CT-scans at the level of the third cervical vertebra (CT-slice at C3) also demonstrated a ring-like enhancement of the right ECA and ICA, and no passage of contrast material was seen in the lumen of these two vessels.
Discussion

The combined application of the cv-Doppler examination and sequential CT-scans with contrast enhancement at the level of the CCA and distal to the carotid bifurcation has proved to be a reliable noninvasive diagnostic tool to detect a CCA obstruction, and to examine the collaterals bypassing the obstruction to fill the ECA, as well as the patency of the ICA in the presence of the CCA occlusion. The reliability was confirmed in all our patients by angiography and/or operation.

CV-Doppler examination of the extracranial cerebral arteries based on indirect and direct criteria alone is a reliable method to detect major ulcerated lesions, stenoses which reduce blood flow in the vascular territory distal to the lesion, and occlusions in the carotid, subclavian, and vertebral arteries. Furthermore, major collaterals bypassing a high-grade obstruction can be detected even in complex pathological vascular situations with extracranial multi-vessel disease. With additional identification procedures and oscillation manoeuvres the individual branches of the ECA, the patency of the proximal ECA and ICA, and the collaterals to the ECA in the presence of an occlusion of the CCA can be evaluated. CV-Doppler, however, is not a 100% reliable method to detect the patency of the ICA in the presence of a CCA occlusion as demonstrated in one of our patients (K.G. in table 1). Very reduced blood flow signals may not allow proper identification of the target artery. Flow direction in the ECA cannot be used as a reliable parameter in all cases since the course of the artery may be coiled. Thus, following the ECA backwards to the carotid bifurcation an ICA-like vessel cannot be suspected in some patients, especially in those with very weak collateral blood flow to the ICA. Even with minimal blood flow, however, thrombus formation may not continue beyond the carotid bifurcation, and enough metabolites may then still be supplied to the inner structures of the ICA, thus keeping the integrity of the arterial wall intact.

Sequential CT-scans with intravenous bolus injection of contrast material at the level of the CCA and distal to the carotid bifurcation alone will demonstrate an occlusion of the CCA by a ring-like enhancement of the vasa vasorum, as well as patency or occlusion of the ECA and ICA in the presence of the CCA occlusion. CT-scans without contrast enhancement will only demonstrate calcified lesions if the scans are taken at the appropriate levels, as demonstrated by Frisén and coworkers and in one patient of our series with an additional calcified lesion at the level of the carotid bifurcation opposite the occluded CCA (patient F.A. in table 1). The method, however, will not show non-calcified stenoses of other extracranial cerebral arteries, as demonstrated in another patient of our series (patient P.E. in table 1). Furthermore, the collateral flow situation to bypass the CCA occlusion and to the ECA cannot be identified by sequential CT-slices at only 2 different levels. Thus, the combined application of cv-Doppler and sequential CT-scans is necessary to evaluate the complete extracranial vascular situation in a given patient with special emphasis to detect a patent ICA in the presence of a CCA occlusion.

Cerebral angiography will demonstrate minor and major obstructions in the extra- and intracranial cerebral arteries and collateral blood flow along different pathways, especially in patients with high-grade ICA obstructions. In the presence of a CCA occlusion, however, routine angiography will not show the patency of the ICA in its full extent in most patients, especially in those with weak but still sufficient collateral blood flow from the ECA to the carotid bifurcation. The patency of the ECA could only be suspected in 2 of our patients angiographically with proved patency by the cv-Doppler-sequential CT-scans method and operative findings respectively. Even the patency of the ECA can be equivocal angiographically, as demonstrated in one of our patients (patient P.M. in table 1). Thus, the combined application of the cv-Doppler-sequential CT-scans method may help to decide for further injections and projections during cerebral angiography, if the results of both diagnostic procedures do not coincide. Furthermore, the combined method
may also be useful in patients who already underwent angiography, but had unclear findings concerning the patency of the ICA in the presence of a CCA occlusion, or in patients with a pseudo-occlusion of the ICA angiographically, or even with an occlusion over a short portion of the ICA at the level of the carotid bifurcation. 15, 17, 27, 28

Does the “noninvasive” knowledge of a patent ICA in the presence of an occluded CCA influence therapy in a given patient with TIA or minor stroke in the carotid territory on the side of the occlusion? If the ECA alone is patent and collateral blood flow to bypass the occlusion is considered insufficient, or distal stump emboli through the ophthalmic artery are thought responsible for the clinical events, then thrombendarterectomy of the CCA or bypass graft operation from a patent vessel to the ECA may be useful. 22-26 If the ICA is also patent, however, thrombendarterectomy of the CCA may be even more beneficial or be the indication for surgery in a given patient. 3, 10, 29, 31 This was confirmed by our patient series of whom only one patient had a successful restoration of blood flow from the CCA to the ICA and 4 patients had unsuccessful surgical exploration of the carotid bifurcation, as predicted by the cv-Doppler-sequential CT-scans method. Thus, surgical exploration of the carotid bifurcation is not necessary in patients with CCA occlusion and questionable patency of the ICA in the angiograms, as proposed by Podore and coworkers, if the findings of the combined noninvasive method are unequivocal. 10

Are there other noninvasive methods reliable enough as to influence further diagnostic work-up and therapy in a given patient with patency of the ICA in the presence of an occluded CCA? Blackshear et al 18 described their experience with an ultrasonic Duplex system in 3 patients with a CCA occlusion. Collateral blood flow from the ECA to the carotid bifurcation into the proximal segment of the ICA was found in all 3 cases. The Duplex-method alone, however, does not give reliable information on the patency of the vertebral and subclavian arteries, nor on the collateral flow patterns to the ECA and to bypass the obstruction. Furthermore, it may not be available in many hospitals, since the device is much more expensive than continuous-wave Doppler equipment.

Intravenous digital subtraction angiography may prove reliable enough to evaluate ICA patency in patients with CCA occlusion. The exact place in evaluation of extra- and intracranial vascular disease, however, remains to be defined, especially in those patients such as ours. 32 Therefore, reliable results from more than one diagnostic method may make decision for optimal treatment in a given patient more appropriate.

To conclude, the combined application of cv-Doppler examination of the extracranial cerebral arteries and sequential CT-scans with intravenous bolus injection of contrast material is a reliable method to evaluate the extracranial vascular situation in a given patient with cerebrovascular disease. The patency of the ICA in the presence of a CCA occlusion can be evaluated, thus helping to decide for further diagnostic work-up and/or (successful) surgical intervention to restore blood flow in the CCA and ICA, especially in those patients with TIA or minor stroke appropriate to the side of the lesion. Thus, even a patient not considered amenable to surgical correction by angiography can benefit of the combined diagnostic tool. 1, 2, 9, 29, 30, 31

References
Cranial Nerve Paralysis Following Carotid Endarterectomy

E. WAYNE MASSEY, M.D., ALBERT HEYMAN, M.D., CAROL UTLEY, CAROL HAYNES, A.B., AND JAMES FUCHS, M.D.

SUMMARY During the past seven years 347 patients have been entered into a data bank at the Duke University Medical Center for evaluation of transient neurologic ischemia. One hundred fifty eight of these patients underwent carotid endarterectomy. Neurological follow-up revealed that 24 (15.1%) of the operated patients had 26 (16.4%) peripheral cranial nerve palsies. Injury to the peripheral portion of the hypoglossal nerve was noted in 13 patients, to the cervical branch of the facial nerve in five and to the recurrent laryngeal nerve branch of the vagus in eight. Complete recovery of nerve function usually occurred within four months but residual deficit was present at one year in two patients with facial nerve and four with hypoglossal nerve involvement. Even though these complications of carotid endarterectomy are generally benign and transient, the frequency of occurrence can be reduced if careful attention is given to anatomic localization of the cranial nerves during surgery.

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THE RELATIONSHIP OF CAROTID ARTERY OCCLUSION AND DISTAL PATENCY/Keller et al


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