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

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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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sary in most diagnostic work-up in a given patient for the experienced examiner.18-20

Carotid artery Doppler is based on direct and indirect criteria.11, 12, 14 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 retroonsilar 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 collateral reserve of the extracranial vascular system may influence the decision for further diagnostic work-up and treatment.11-14 For subclavian artery Doppler the probe is held in a latero-medial direction in the supraclavicular region. Oscillation manoeuvres on the homolateral upper arm are used to identify the artery, in addition to its flow characteristics. For vertebral artery Doppler, flow signals from the VA are picked up near its branching point from the subclavian artery, from the middle cervical portion by the transoral approach, and from the atlas loop in the region of the mastoid.15, 14 Oscillation manoeuvres over the atlas portion of the VA additionally help to identify the target artery.11, 14

Computed tomography of the neck was first described to identify calcified lesions in the extracranial carotid arteries in TIA patients.21 Rapid-sequence or dynamic computertomographic scanning with sequential scans at the same cross section and with intravenous bolus injection of contrast material (sequential CT-scans) has been used to evaluate cerebral blood flow and the patency of the carotid artery distal to an occlusion.15-17 Sequential CT-scans with rapid bolus injection of 70 to 100 ml of Telebrix were used in our series to determine the patency of the CCA, ICA and ECA and to confirm and complete cv-Doppler results. Hereby, passage of the contrast bolus through a patent CCA was usually visible in more than one slice at the level of the fifth or the sixth cervical vertebra. If the artery was occluded, however, a ring-type enhancement of the vasa vasorum of the CCA occurred with the lumen of the artery free of contrast material. Sequential CT-scans distal to the carotid bifurcation, usually at the level of the third or the fourth cervical vertebra, demonstrated passage of the contrast bolus through a patent ECA and ICA. Hereby, the lumen of the ECA and ICA was filled with contrast material even in the presence of a CCA obstruction, if collateral blood flow existed. There was, however, a time delay of the bolus passage as compared to the contralateral side. If the ICA was occluded a ring-type enhancement of the vasa vasorum of the ICA was observed, while delayed contrast bolus passage was present in a still patent ECA. Thus, normal or delayed passage of the contrast bolus through the ECA and ICA in the presence of an occluded CCA was thought to indicate sufficient collateral filling of these arteries and patency of the ICA was assumed.

**Patient Material and Results**

Seven patients with an occluded CCA (2 patients on the right side, 5 patients on the left side), proved by cv-Doppler and angiography, were used to demonstrate the validity of the combined cv-Doppler-sequential CT-scans method in evaluating the patency of the ECA and the ICA on the side of the occlusion, the collaterals used to bypass the occlusion and, those collaterals filling the ECA. The history of the patients, the clinical findings, the results of the cv-Doppler examination and of the sequential CT-scans method, the results of cerebral angiography and therapy are depicted in table
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. 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-
Figure 2. 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 atlantoaxial portion of the left VA could be registered from the left ECA (see figure 1). 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 future. 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 intervenous 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.
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 suprabrowial 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.
sion of the right CCA with collateral blood flow from branches of the left ECA to the right ophthalmic artery. Blood flow signals from the right ECA were detectable, but much weaker than those on the left side, and no ICA-like blood flow signals could be registered. Oscillations generated in the right VA by digitally tapping its atlas portion propagated to the right ECA, indicating collateral blood flow from the right VA to branches of the right ECA only. Sequential CT-scans with contrast enhancement at the level of the 5th cervical vertebra showed a ring-like enhancement of the vasa vasorum of the right CCA, indicating an occlusion of the artery below this level. Passage of the contrast bolus through the left CCA was normal. Furthermore, at the level of the 3rd cervical vertebra a normal passage of contrast material was observed in the left ECA and ICA, but a ring-like enhancement of the vasa vasorum of the right ECA and ICA occurred. Contrast material, however, was seen in smaller vessels frontal to the right ECA. Thus, patent branches of the right ECA had to be assumed. Sequential CT-slices at the level of the 2nd cervical vertebra showed an occluded right ICA and a fully patent right ECA. Angiography demonstrated an occlusion of the right CCA at the level of the seventh cervical vertebra and filling of branches of the right ECA from the right VA through muscular branches. CCA endarterectomy was not performed, since collateral blood flow from the left ECA to the ophthalmic artery was high and was not thought to improve by additional flow from the right CCA to the homolateral ophthalmic artery through the right ECA. Furthermore, patency of the right CCA could probably not be restored, since fibroses after X-ray treatment had to be assumed, and a similar operation failed in another patient who also had X-ray treatment 22 years before admission (patient P.E. in table 1).

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.11-14 Furthermore, major collaterals bypassing a high-grade obstruction can be detected even in complex pathological vascular situations with extracranial multi-vessel disease.11-14 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.9,10

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 coworkers15 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.9 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. 16, 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. 22-28 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 amendable to surgical correction by angiography can benefit from the combined diagnostic tool. 1, 2, 9, 29, 30, 31

References


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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 with symptomatic "carotid occlusion" referred for extracranial occlusive disease. Arch Neurol 30: 791-801, 1967

Methods and Results
Since 1973 the Division of Neurology of the Duke University Medical Center has maintained a computerized data bank of patients with symptoms of transient neurologic ischemia. Certain patients among the group had carotid endarterectomy if they had appropriate extracranial lesions. Three hundred forty seven patients with focal transient cerebral ischemic symptoms were entered into this program from 1974 to 1978, and 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%) instances of peripheral cranial nerve palsies. The deficits consisted of 13 cases of hypoglossal nerve palsy (8%), five cases of palsy of the cervical branch of the facial nerve (3%), and eight cases of vocal cord paralysis (5%). Ages ranged from 47 to 77 years of which eleven patients were female and 13 were male. Mean age was 62.1 years, only slightly higher than among patients with carotid endarterectomy uncomplicated by cranial nerve palsy (61.2 years). There were six instances of subsequent major clinical events over a three

THE RELATIONSHIP OF CAROTID ARTERY OCCLUSION TO CEREBROVASCULAR SYMPTOMS has undergone an evolution in understanding and management. A prominent feature of this change is represented by the fact that over the past thirty years, operative removal of carotid lesions has become a standard therapeutic choice when occlusive or ulcerative plaques serve as central nervous system complications, i.e. stroke and transient ischemic attacks. Another complication which merits additional investigation is the occurrence of peripheral neurologic deficits that may lead to functional and cosmetic defects. Surprisingly little emphasis has been given to this problem and this has prompted the present investigation of cranial nerve symptoms in a group of patients undergoing carotid endarterectomy for transient ischemic attacks.

Patency of external and internal carotid artery in the presence of an occluded common
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