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Intravenous Digital Subtraction Angiography: An Index of Collateral Cerebral Blood Flow in Internal Carotid Artery Occlusion

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SUMMARY The objective of this investigation was to correlate Xenon-133 inhalation rCBF measurements with the pattern of cortical arterial filling on intravenous DSA in 18 patients with unilateral internal carotid artery occlusion. Of 9 patients showing symmetrical filling of hemispheric cortical arteries, none showed an inter-hemispheric difference in rCBF (ΔFg) greater than 10ml/100gm/min. Of 9 patients showing delayed cortical opacification ipsilateral to the internal artery occlusion, 3 showed a ΔFg greater than 10ml/100gm/min, 3 showed a ΔFg in the 7–10ml/100gm/min range, and 3 had a ΔFg less than 7ml/100gm/min. All patients with asymmetric abnormalities in the rCBF profile had the delayed pattern of cortical filling on DSA. The presence of symmetrical hemispheric opacification of cortical arteries on DSA indicates adequate interhemispheric redistribution of rCBF and patent inter-hemispheric collateral channels, but not necessarily normal cerebral blood flow. The presence of delayed cortical arterial opacification on the side of internal carotid artery occlusion does not necessarily imply significant inter-hemispheric rCBF differences, nor does it rule out a normal rCBF. The presence of bilateral reduction of rCBF and symmetrical cortical arterial filling on DSA may represent an “interhemispheric steal.”

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AFTER UNILATERAL INTERNAL carotid artery (ICA) occlusion, regional cerebral flow (rCBF) in the ipsilateral hemisphere reflects the adequacy of collateral circulation from the contralateral ICA, the vertebrobasilar system and from other sources.1,2 Quantification of collateral flow might clarify the ischemic nature of patient symptoms and could affect therapeutic decisions.1,3,4 Conventional angiography can only visualize patterns of collateral circulation originating from the injected artery. This may be a misleading index of overall collateral blood flow. Since intravenous digital subtraction angiography (DSA) simultaneously delivers contrast material into the territory of an occluded ICA from all possible collateral sources,5 DSA allows an examination of the distribution of arterial blood to the hemisphere on the side of the ICA occlusion. The objective of this investigation was to correlate Xenon-133 inhalation rCBF measurements with the pattern of opacification of cortical vessels on DSA in 18 patients with unilateral ICA occlusion.

Methods

Eighteen patients (mean age 57 years) with unilateral ICA occlusion underwent Xenon-133 inhalation rCBF measurement and DSA as part of their evaluation by the Cerebrovascular Section of the Cleveland Clinic. One patient had occlusion of the ICA secondary to a medial sphenoid ridge meningioma. All other patients had atherosclerotic occlusion of one ICA with varying degrees of contralateral disease. All patients presented with recent stroke, transient ischemic attacks and/or amaurosis fugax ipsilateral to the occluded ICA. The rCBF studies were carried out in a quiet, darkened room. The patients inhaled 20 mCi of Xenon-133 through a mouthpiece designed to eliminate leakage of gas. Radiation over the cranial vault was detected...
using sixteen 1.3 cm × 1.3 cm scintillation detectors (8 overlying each hemisphere). The detectors were mounted on a frame which was positioned according to standard skull landmarks thereby maximizing the reproducibility of detector placement. Expired air was sampled for end expiratory radiation counts which were assumed to parallel arterial Xenon-133 concentrations in the absence of pulmonary disease. The Xenon washout curves were then analyzed using a 2-compartmental model as described by Obrist et al.\textsuperscript{6} A gray matter flow (Fg) was calculated for each detector. An initial slope index (ISI) was also derived from analysis of the washout curves as described by Blaunstein et al.\textsuperscript{7} Mean hemispheric Fg and mean hemispheric ISI were then computed using the flow rates and slope indices from the detectors overlying each hemisphere. Previous experience with this system has established a mean normal hemispheric Fg of 74 ± 9 ml/100gm/min and a mean normal hemispheric ISI of 56 ± 8.\textsuperscript{4} A focal rCBF abnormality (F) was defined as an Fg and/or ISI value less than two standard deviations of the normal mean (Fg ≤ 56 ml/100gm/min and/or ISI ≤ 38) in at least one detector. A diffuse rCBF abnormality (D) was defined as multiple focal abnormalities resulting in a hemispheric mean Fg and/or hemispheric mean ISI less than two standard deviations of the normal mean.\textsuperscript{3,4} Details of the DSA methodology have been published previously.\textsuperscript{5,8,9} Images were obtained on a specially designed prototype digital subtraction system. Video information was collected and the signal was logarithmically amplified, digitized and directed to one of two memories for storage, integration and display. Prior to the arrival of contrast material at the region of interest, fluoroscopic images were converted to digital data for storage in one of the memories. This digitized data, termed the ‘‘mask image,’’ was either a single frame or the integration of several frames. The subsequent images, also digitized, had the mask image subtracted from them and the resultant images were viewed in real time. Each image represented computed integrated data over 1 second. Recent modifications in the instrumentation, including the conversion from a 256 × 256 to a 512 × 512 matrix, have improved visualization of intracranial vessels.

The DSA studies were graded by our neuroradiologist (MTM) who was blinded to the rCBF data. At the end of each DSA study the sequence of vascular filling was examined in the standard anteroposterior and lateral projections. The extent of cortical arterial filling ipsilateral to the ICA occlusion was estimated at the time of best cortical arterial filling in the opposite hemisphere. The DSA filling time was classified as ‘‘delayed,’’ (fig. 1) or ‘‘equal’’ (fig. 2).

**Results**

The rCBF data and cortical filling patterns on DSA are summarized in table 1. Nine patients had delay in hemispheric cortical artery opacification on DSA ipsilateral to the ICA occlusion. Of the 9 patients with delayed cortical arterial filling, 5 had diffuse ipsilateral rCBF abnormalities with focal abnormalities contralaterally, 3 had normal rCBF bilaterally and 1 patient had bilateral diffuse rCBF abnormalities. Of the 9 patients with detectable delay in cortical filling on DSA, 3 had a mean inter-hemispheric difference in rCBF (ΔFg) of less than 7 ml/100gm/min. Three had a ΔFg in the 7–10 ml/100gm/min range, and 3 had a ΔFg greater than 10 ml/100gm/min.

All 9 patients with no detectable delay in hemispheric cortical arterial opacification on DSA had identical rCBF profiles in both hemispheres. Four patients had normal rCBF bilaterally, 4 had diffuse rCBF abnormalities bilaterally and 1 had bilateral focal abnormalities. Of the 9 patients with equal opacification,
FIGURE 2. Intravenous digital subtraction angiogram of patient #17. Patency of the anterior circle of Willis is demonstrated with cross-filling of the left A1 segment (single arrow). Opacification of the cortical arteries in both hemispheres is simultaneous despite the occluded left ICA. The patient had a negligible interhemispheric ΔFg.

One patient exhibited a ΔFg in the 7–10 ml/100 gm/min range and 8 patients had a ΔFg of less than 7 ml/100 gm/min.

None exhibited a ΔFg of more than 10 ml/100 gm/min.

Discussion

In a previous clinical and angiographic correlation of Xenon-133 inhalation rCBF measurements in 88 patients, we found that 28% of patients with unilateral carotid occlusion had a ΔFg of more than 10 ml/100 gm/min.
ICA occlusion had normal rCBF profiles. Of the remaining 72%, half had bilateral diffuse decrease in rCBF. Patients with severe symptomatology were more likely to show abnormal rCBF patterns. We partly attributed these findings to variability in collateral blood flow to the territory of the occluded ICA.

Although Xenon-133 inhalation rCBF measurements can be performed noninvasively with relative ease and good reproducibility, their application to the management of patients with cerebrovascular disease remains unclear. At the same time, DSA is gaining acceptance as a practical alternative to conventional arteriography in selected patients with carotid artery disease. Because it delivers contrast simultaneously to all vessels, DSA is potentially a useful index of collateral cerebral blood flow in patients with ICA occlusion. We found that the presence of symmetrical hemispheric filling of cortical arteries on DSA in patients with ICA occlusion indicated negligible inter-hemispheric rCBF differences in all cases. The presence of a delayed pattern of filling on DSA ipsilateral to ICA occlusion, however, was not always accompanied by significant inter-hemispheric rCBF differences. Since only larger cortical arteries can be visualized by DSA, and since rCBF reflects total flow in larger and smaller vessels, a delay in opacification does not necessarily represent a decrease in rCBF.

The presence of symmetrical hemispheric arterial filling on DSA does not imply normal cerebral blood flow. Such a pattern on DSA only indicates functional inter-hemispheric collateral channels. With further compromise of the circulation to the brain (i.e., significant stenosis of the contralateral carotid artery or the vertebrobasilar system), such patent collaterals can result in “inter-hemispheric steal” and symmetrically decreased rCBF bilaterally. Five of our patients had symmetrical cortical artery filling on DSA and bilateral reduction of rCBF. In a previous study of rCBF using positron emission tomography in a small number of patients undergoing STA-MCA bypass surgery for ischemic symptoms on the side of ICA occlusion, there was improvement of rCBF in both hemispheres postoperatively, where bilateral rCBF reduction was present preoperatively. These findings substantiate the possibility of “inter-hemispheric steal” in these patients.

Only a qualitative index of collateral blood flow can be derived from this techniqiue. However, DSA in unilateral ICA occlusion can provide useful information about the functional patency of collateral channels which can be correlated with rCBF data to provide insight into cerebrovascular hemodynamics.

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