Carotid-cavernous fistula

Demonstration of asymptomatic vascular "steal"

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Abnormal distribution of cerebral vascular flow was studied in a patient who had a traumatic carotid-cavernous sinus fistula. Serial studies were performed using a method for determining relative cerebral vascular flow: 99mTc-diethylene-triamine pentaacetic acid (99mTc-DTPA) was injected intravenously and flow data were processed by a digital computer. Serial studies documented the occurrence of a vascular "steal" during temporary carotid occlusion; postoperative studies showed disappearance of the steal and obliteration of the fistula. This method for performing vascular flow studies may have broad applications in detailing arterial structures and capillary filling in the brain, and in demonstrating alterations in the cerebral circulation.

KEY WORDS • cerebral blood flow • computerized nuclide brain scan • vascular "steal" • carotid-cavernous fistula

Vascular "steal" has important clinical consequences, in that cerebral hypoxia resulting from the steal may produce transient or permanent neurological deficits. Intracerebral steal occurs in association with a variety of pathological conditions, including arteriovenous malformations (AVM's), meningiomas, carotid occlusion, and carotid-cavernous fistulas. Reports in the literature have verified that in some cases the neurological deficits accompanying these conditions may be attributable to ischemia in an underperfused normal brain resulting from vascular steal, rather than to a local effect of the lesion itself.

In order to investigate the abnormal distribution of cerebral blood flow (CBF) induced by this type of lesion, we used a computerized radionuclide brain-scanning procedure for the scintigraphic analysis of cerebrovascular flow in a patient who had a traumatic carotid-cavernous sinus fistula. With this rapid, dynamic procedure, we performed serial studies that determined relative CBF and documented the occurrence of a vascular steal during temporary carotid occlusion.

Materials and Methods

The patient was positioned under a Searle Pho/Gamma IV scintillation camera* for an

*Searle Pho/Gamma IV scintillation camera manufactured by Searle Radiographics, Division of Searle Diagnostics Inc., 200 Nuclear Drive, Des Plaines, Illinois.
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Fig. 1. Graph of counts of equal areas of the right and left hemispheres from the time of injection, 0 to 50 seconds. Inset: Left carotid occlusion, preoperative study. The peak count rate in the right hemisphere (area B) is higher and occurs 4 seconds earlier than the peak in the left hemisphere (area A).

Equal-area regions of interest were placed over appropriate parts of the flow image, and counts per unit time were plotted for the whole sequence of images. On the anterior view, two rectangular regions were placed symmetrically over the hemispheres, avoiding the sagittal sinus and the region of major branching from the circle of Willis. The region in which the curve first reached peak count rate was then selected, and a printout of the entire curve was generated in order to avoid incorporating the peak or the downslope in any of the data (Fig. 1). The time interval from the initial rise in count rate to one frame before peak activity, which lasted only a few seconds, was selected on the basis of the fastest curve.

The designated frames were then added by the computer and presented on the video screen as the "functional flow image," a map in which each of the picture cells on the screen represented the integrated upslope of the early rising portion of the perfusion curve over that specific region of the brain. Total counts in symmetrically placed regions of the

anterior Towne or left lateral view. A bolus of 15 to 30 mCi of the radionuclide, $^{99m}$technetium-diethylenetriamine pentaacetic acid ($^{99m}$Tc-DTPA), was rapidly injected intravenously. Flow data were collected by a computer† in 1.25-second histograms (64 × 64 matrix) for 50 seconds after injection.

For orientation and clinical review, a "movie-like" dynamic playback of the consecutive 1.25-second images was displayed in color on the video screen of the computer. Regions of interest were designated on the video screen, and quantitative data were displayed in the form of computer-generated graphs of count rate versus time. A composite "functional flow image," which represented most accurately the blood perfusion features of the study, was created by adding the individual frames of the dynamic histogram in the early phase of the study, as follows.

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map in the anterior projection were used for quantitative comparisons (see Discussion for rationale). These total counts were termed “flow-image counts” (Table 1).

**Case Report**

Four months before this 37-year-old man was admitted in October, 1976, he had been hit on the left side of his face with a board and rendered unconscious for 3 minutes. Upon awakening, he noticed a bruit in his left ear. The bruit became bilateral 2 weeks later, at which time the patient also had diplopia in all directions of gaze, unilateral proptosis with conjunctival injection, and occasional headaches in both supraorbital regions.

*Examination.* Proptosis (6 mm) on the left was associated with conjunctival chemosis, pronounced congestion, and arteriolization of conjunctival vessels. In the left eye, visual acuity was decreased (20/30), extraocular movements were restricted in all directions, and intraocular pressure was abnormally high (32 mm Hg). Treatment with Diamox (acetazolamide) was initiated. Examination of the fundus disclosed bilateral venous dilation and several hemorrhages and cotton-wool spots in the left eye. Sixth nerve paresis was found in the right eye. The rest of the central nervous system examination was normal. A loud bruit, audible throughout the cranium, was loudest in the left periorbital region. Left common carotid compression abolished the bruit.

Bilateral selective internal and external carotid and left vertebral arteriograms showed a carotid-cavernous fistula in the midportion of the horizontal segment of the left intracavernous internal carotid artery (ICA) (Fig. 2). All contrast material injected into the left ICA entered the cavernous sinus and drained rapidly into adjacent deep and superficial venous structures. Left external carotid injection revealed retrograde flow in the ophthalmic artery; right internal carotid and left vertebral injections each filled all major intracranial vessels and the left cavernous sinus through large anterior and posterior communicating arteries. Right internal carotid and left vertebral arteriograms performed during temporary left common carotid occlusion demonstrated rapid filling of the cavernous sinus by retrograde flow through the distal left ICA.

The $^{99m}$Tc-DTPA flow study in the left lateral projection showed rapid flow through

**Table 1**

<table>
<thead>
<tr>
<th>Study</th>
<th>Flow Image Counts</th>
<th>Vascular Flow</th>
<th>Delay To Peak Filling of Left Hemisphere (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>preoperative</td>
<td>Left: 1380</td>
<td>Right: 1183</td>
<td>Lt:Rt Ratio: 1.2:1 Relative Change (%): 32:1</td>
</tr>
<tr>
<td>carotid occlusion (preop)</td>
<td>2241</td>
<td>3217</td>
<td>0.7:1: 42</td>
</tr>
<tr>
<td>postoperative</td>
<td>1237</td>
<td>1081</td>
<td>1.1:1</td>
</tr>
</tbody>
</table>

**Fig. 2.** Left common carotid arteriogram, lateral projection. Contrast material introduced into the left common carotid artery rapidly opacifies the cavernous sinus (1), superior ophthalmic vein (2), basal vein (3), straight sinus (4), sphenoparietal sinus (5), superior sagittal sinus (6), and the pterygoid venous plexus (7). Neither the supracavernous portions of the internal carotid artery nor its intracerebral branches are opacified.
FIG. 3. Upper: Functional flow image, left lateral projection. The color stripe (center) includes 15 color units that correspond to the relative count rate from 0% (deep blue) to 100% (white). The color of each picture cell of the functional image corresponds to the flow image counts accumulated in that square. Upper Left: Preoperative study. The carotid-cavernous fistula and prominent venous structures are seen. Superior ophthalmic vein: open arrow, torcular: closed arrow, and fistula: black arrow. Compare to Fig. 2. Upper Center: Left carotid occlusion (preoperative study). Venous structures are seen, unchanged from A. Upper Right: Postoperative study. Normal arterial pattern. Note the absence of the fistula, veins, and venous sinuses. Lower: Functional flow image, anterior Towne projection. Lower Left: Preoperative study. There is nearly symmetrical filling of the right and left hemispheres (arrows). Lower Center: Left carotid occlusion (preoperative). There is a decrease in vascular flow to the left hemisphere (arrow), demonstrating a vascular steal. The carotid cavernous fistula is filling via retrograde flow. Figure 1 shows graphic presentation of this study. Lower Right: Postoperative study. The left carotid is occluded and the fistula is not filling. The vascular flow to the hemispheres is nearly symmetrical.

the left ICA into the cavernous sinus and associated draining veins (Fig. 3 upper); in the anterior Towne projection, it showed that the left hemisphere filled more slowly than the right (Fig. 3 lower). The peak count rate occurred 2 seconds later in the left hemisphere than in the right. The integrated "flow-image counts" in two comparable areas of the left and right hemispheres (1380 and 1183, respectively) gave a left:right vascular flow ratio of 1.2:1 (Table 1). Therefore, although the flow to the left was delayed, the total count was slightly but not significantly greater on the left because of rapid venous filling.

A flow study (anterior Towne projection) performed during temporary left carotid artery occlusion (Fig. 3 right) showed even slower filling of the left hemisphere (4-second delay); the left:right vascular flow ratio was 0.7:1, which represented a 42% decline in flow to the left in comparison with the non-occlusion study (Table 1). No ischemic symptoms occurred during the compression studies.

Operation. The left common, internal, and external carotid arteries in the neck were exposed, and a catheter was placed in the left femoral artery for intraoperative vertebral arteriography. A flexible No. 5 French intra-
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Fig. 4. Left eye. The preoperative photograph (left) shows proptosis with congestion and arterialization of the conjunctival vessels. The postoperative photograph (right) shows resolution of these changes.

cranial arterial occlusion catheter with an injection port proximal to an inflatable latex rubber balloon was passed into the ICA through a small arteriotomy and was positioned under radiographic control so that, when inflated, it simultaneously occluded both the fistula and the adjacent carotid artery. When the balloon was inflated in the proper position the bruit immediately ceased, contrast material injected proximal to the balloon remained in the occluded left carotid artery, and intraoperative vertebral angiography revealed no retrograde filling of the fistula and good opacification of the left hemisphere vasculature. This verified that the left ICA and the origin of the fistula were occluded by the balloon. The left ICA was ligated at its origin, and the residual catheter material placed in a pocket along the carotid sheath.

Postoperative Course. Recovery following surgery was uncomplicated. Repeat right carotid and left vertebral arteriography disclosed normal intracranial vasculature, including anterograde flow in the left ophthalmic artery without opacification of the cavernous sinus. A radionuclide study (anterior projection) showed essentially no difference between the flow to the left and right hemispheres (Fig. 3 lower); the flow ratio was 1:1 (Table 1). The lateral study showed a normal arterial pattern; no venous structures were seen (Fig. 3 upper).

Proptosis and chemosis decreased immediately (Fig. 4). By the third postoperative day, the extraocular movement abnormalities and diplopia had disappeared. Three months after surgery, the patient's visual acuity and intraocular pressure were normal. The results of the visual evoked response test and fluorescein retinal angiography were normal. The headache and bruit had not recurred.

Discussion

Several methods have been applied to evaluate altered blood flow arising from vascular steal in various pathological states. Using electromagnetic flow probes placed on the cervical and intracranial carotid arteries during surgery, Nornes measured the degree of steal in five patients with carotid-cavernous fistula, and documented disappearance of steal after trapping and muscle-embolization of the fistula. Herrmann, et al., used 99mTc-albumin macroaggregate scintigraphy to show diversion of blood flow from a contralateral carotid through a carotid-cavernous fistula to the lung. Hachinski, et al., and Michelsen, et al., using regional cerebral blood flow (rCBF) by carotid injection of xenon-133 (133Xe), showed focal tissue hypoperfusion in brain adjacent to an arteriovenous malformation (AVM); after the AVM was resected, the flow increased and rCBF returned to normal in the surrounding hemisphere.

The method for assessing relative cerebral vascular flow using 99mTc-DTPA, which was designed on the basis of work by Sapirstein, Moses, et al., Wagner, and DeLand, was

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3Catheter manufactured by Edwards Laboratories, Santa Ana, California.
developed as an alternative to the use of injected microspheres. While microsphere injection is the best established method of fractionating blood flow, its use in brain studies carries the risk of inducing embolic neurological deficit. Moses, et al., and Wagner showed that the rates at which intravenously administered $^{99m}$Tc-DTPA and microspheres arrive in the brain are almost identical. Both substances achieve similar distribution in the brain during the time interval before significant washout of DTPA; however, it is important to ensure that the relative distribution of $^{99m}$Tc-DTPA is determined before washout occurs. With the use of a computer to identify the arrival time by displaying the appearance of the radionuclide in the brain as a graph of counting rate versus time, as in this method, the activity in any region of interest in the brain can be visualized. The upslope portion of the curve represents the arrival of the radionuclide in the brain before any washout occurs; the computer integrates the counts for the time interval of the upslope of the curve and presents the integrated data as a “functional image” of relative CBF on the video screen.

In normal patients, the functional image details the major arterial structures and the capillary filling of the brain; no venous structures are seen. Our patient's preoperative functional image showed only filling of cerebral cortical veins and venous sinuses resulting from the carotid-cavernous fistula. After surgical occlusion of his fistula, a repeat study showed a normal arterial pattern.

Alterations in the cerebral circulation can be measured using another application of this method. When a study is performed with the head in the anterior Towne projection, the distribution of blood to the right and left hemispheres can be compared; both the arteriogram and the radionuclide studies revealed that the left ICA did not contribute to the left cerebral circulation. Nevertheless, the circulation to the left hemisphere was adequate, as demonstrated by the vascular flow ratio. During a brief preoperative left carotid occlusion, the distribution of blood flow to the brain was altered (Fig. 3 lower). The left:right ratio of the upslope values (0.7:1) showed a 42% decline in the left hemisphere (Table 1), which documented the presence of a vascular steal. Since the right carotid flow was partially diverted to the fistula, relatively less blood was available to supply the left hemisphere. The relative ischemia was quantitated by computer analysis.

Regional blood flow studies using the diffusible radionuclide $^{133}$Xe have provided impetus to the study of abnormalities of brain blood flow. While quantitative $^{133}$Xe studies are a useful research tool, the simpler technique described here is more suited to practical clinical applications.

Although the radionuclide $^{99m}$Tc-DTPA diffuses into extracellular fluid in the minutes following injection, it can be correctly considered intravascular during the first few seconds after injection. During the brief arrival time, which is the time interval used for analysis, it is almost entirely intravascular. In contrast, the activity of $^{133}$Xe is studied as it leaves brain parenchyma, not as it arrives in the brain; quantitative CBF measurements are determined by analyzing the washout of $^{133}$Xe from the brain several minutes following injection. For this reason, $^{133}$Xe studies permit quantitative rCBF measurements, and multiple determinations can be performed during a single examination under varying physiological conditions, such as varying blood pressure or arterial CO$_2$ pressure. However, because $^{133}$Xe studies require intraarterial injection, serial studies are done only rarely. The $^{99m}$Tc-DTPA technique permits two measurements on any one day. Although the data compare the two hemispheres without giving quantitative rCBF information, serial measurements on different days are easily performed, since only intravenous injection is required.

The $^{99m}$Tc-DTPA procedure presented here offers several advantages over transit time measurements and quantitative rCBF studies that involve an analysis of the washout of diffusable, intraarterially administered tracers, such as $^{133}$Xe. It can be performed more economically, safely, and rapidly than these other procedures. In addition, because the radionuclide, scintillation camera, computer, and computer software required for these studies already are widely used in nuclear neuroscience.
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Demonstration of asymptomatic vascular "steal" medicine laboratories throughout the United States, they can be made readily available to the clinician and involve no additional expense for equipment. Future applications of this procedure may include the assessment of patients with aneurysms, cerebral vasospasm, and neoplasms, and the preoperative and postoperative study of patients who are undergoing cerebral revascularization procedures.1,10

References


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