Intravenous Digital Subtraction Angiography of the Nearly Occluded Internal Carotid Artery

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Three patients with nearly occluded internal carotid artery origins were evaluated with intravenous digital subtraction angiography and subsequently had successful carotid endarterectomies. The angiographic features are described. Although conventional arterial angiography offers superior spatial resolution and selectivity, the thorough mixing of blood and contrast medium that occurs with the intravenous technique minimizes the tendency toward layering beyond a high-grade stenosis, which may occur with selective arterial injection. In cooperative patients, the intravenous digital technique may be sufficiently reliable in the detection of the nearly occluded internal carotid artery to obviate conventional selective common carotid angiography.

Intravenous digital subtraction angiography (DSA) has recently become an accepted screening procedure in the evaluation of patients with transient ischemic attacks or stroke [1–4]. Because of limitations in spatial resolution, lack of selectivity, and problems with motion artifacts, concern has been raised that the intravenous technique may miss very high-grade stenoses of the internal carotid artery (ICA), which might otherwise be diagnosed with selective common carotid angiography, and thus possibly lead to incorrect patient management. We describe three patients with nearly occluded ICAs and suggest not only that intravenous DSA is reliable in the diagnosis of this entity, but that it may have certain advantages over conventional angiography.

Materials and Methods

During a 2-year period, over 1000 patients were evaluated for cervicocerebral atherosclerotic disease with an intravenous DSA system developed at the University of Arizona [5]. Most studies were performed with superior vena cava injections of 40–42 ml of Renografin-76 and included arch aortography, both oblique views of the neck, and anteroposterior imaging of the intracranial vessels. The usual imaging sequence was one image per second for 14–20 sec, using 14-inch (35.6 cm), 10-inch (25.4 cm), or 6-inch (15.2 cm) field sizes in conjunction with a 512 × 512 pixel matrix. Radiographic factors were generally 70–80 kVp, 500 mA, and 0.08 sec pulsed exposures using a 0.6 mm focal spot tube.

Thirty patients whose intravenous DSA examinations showed greater than 70% diameter stenosis of one ICA had associated delayed contrast transit through the involved carotid artery and cerebral hemisphere when compared with the opposite side. Some of these patients were the subject of an earlier report [6]. Three other patients, presented here, had even more severe stenosis of one ICA with associated extremely slow flow and marked luminal narrowing. One of these had been misdiagnosed as a complete occlusion of the ICA on the basis of a selective common carotid angiogram. All three underwent successful endarterectomy on the basis of the intravenous DSA findings.

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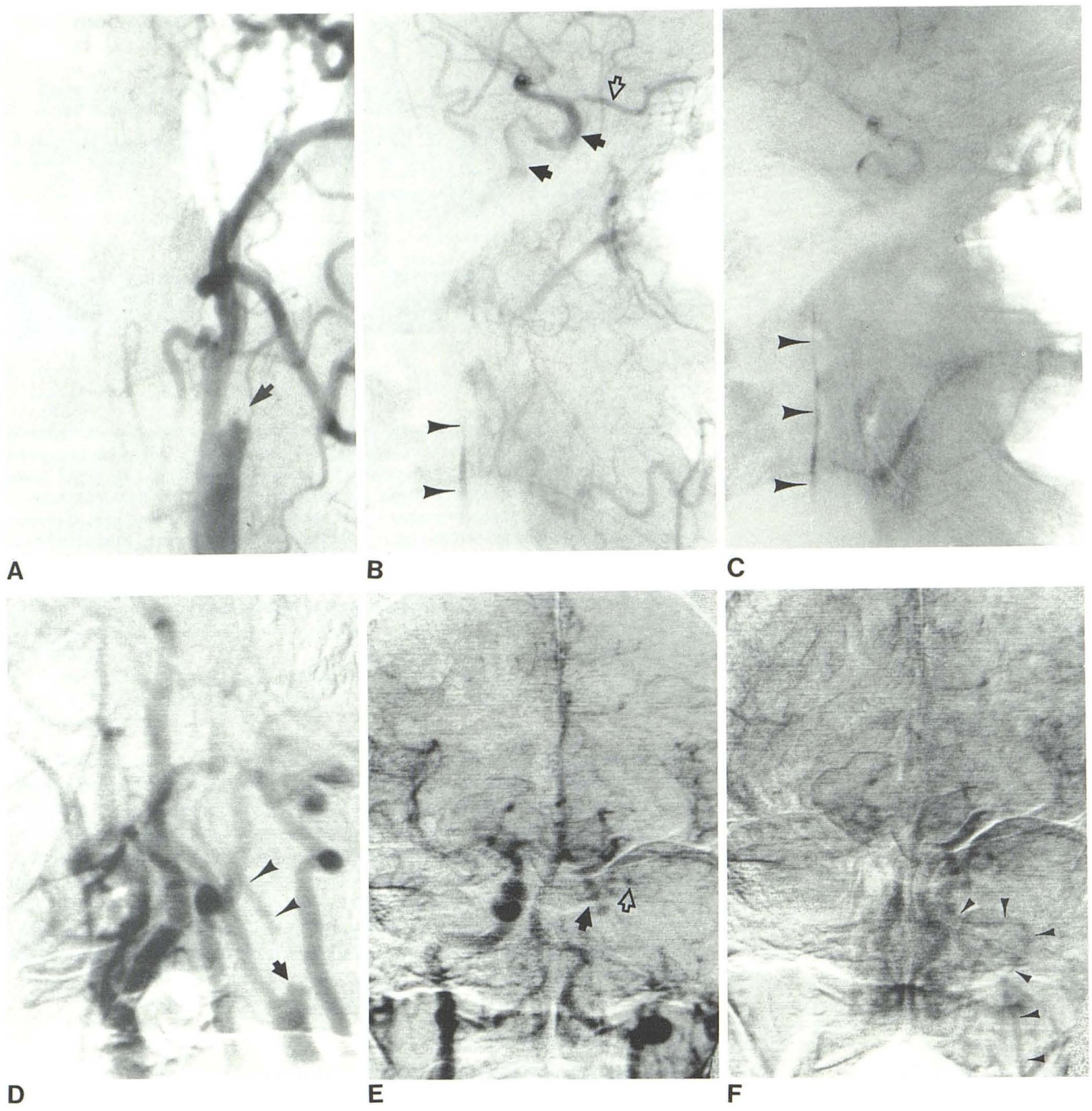

Fig. 1.—Case 1. **A–C**, Left common carotid angiography. **A**, Anteroposterior view. Apparent stump (*arrow*) simulates complete occlusion of ICA. **B**, Lateral head radiograph during late arterial phase. Collateral flow from external carotid branches and ophthalmic artery (*open arrow*) to precavernous and cavernous ICA (*solid arrows*). Thin line of contrast medium begins to ascend posterior wall of ICA (*arrowheads*). **C**, Late head radiograph. Extremely slow ascent of contrast medium (*arrowheads*). **D–F**, Intravenous DSA. **D**, Right posterior oblique image of neck. Opacification of left ICA (*arrowheads*) beginning about 15 mm beyond apparent stump (*arrow*). Stenotic segment cannot be seen. **E**, Anteroposterior view of head 3 sec after arrival of contrast medium. Normal opacification of right ICA and vertebrobasilar system, but only of ophthalmic arery (*open arrow*) and cavernous part of ICA (*solid arrow*) on left. **F**, 2 sec later, after right ICA has cleared, collapsed left ICA is opacified (*arrowheads*).

Case Reports

Case 1

A 62-year-old woman had sudden onset of aphasia with minimal right facial and right arm weakness. After partial recovery with mild residual dysphasia, she underwent selective left common carotid angiography at another hospital, but the study was interrupted by another episode of aphasia. The left ICA was thought to be completely occluded (fig. 1A). She was then referred to our institution for intravenous DSA to rule out significant disease of the right carotid artery

before planned left-superficial-temporal–middle-cerebral-artery bypass surgery.

The intravenous study showed only minimal atherosclerotic changes on the right, but late images revealed slow, antegrade flow through a very small left ICA (figs. 1D–1F). Subsequent review of late films from the conventional angiogram, especially with subtraction, showed a thin line of contrast medium along the posterior wall of the left ICA (figs. 1B and 1C), which indicated a patent vessel distal to a nearly occluded origin. Left carotid endarterectomy with removal of an associated fresh thrombus at the origin of the ICA was accomplished without complications the next day, confirming the interpretation of the intravenous DSA.

Case 2

A 60-year-old woman with a long, complicated medical history had recent onset of severe ischemia of the right foot with gangrene of the right fourth toe. Before scheduled amputation, she experienced several episodes of anomia and left arm weakness. Noninvasive ocular pulse studies were abnormal on the right. An intravenous DSA study of the head and neck revealed mild to moderate stenosis and ulceration of the left ICA origin and a marked delay in opacification of a stringlike right ICA (figs. 2A–2D). On the basis of these findings, right carotid exploration was performed, confirming patency beyond a near total occlusion at the origin of the ICA. No antegrade flow across this stenosis was noted, but there was good retrograde flow after endarterectomy. An intraoperative arteriogram demonstrated patency of the ICA (fig. 2E).

Case 3

A 65-year-old woman had had a left hemispheric stroke 3 years earlier. Except for minimal residual right-sided weakness, she had recovered fully and remained clinically stable over the past 2 years. She was referred to us for current assessment of her extracranial vessels. Intravenous DSA showed moderate stenosis of the distal right common carotid artery and apparent complete occlusion of the left ICA at its origin. However, delayed images showed slow opacification of a very small but still patent left ICA (fig. 3). After deliberation, considering the current absence of clinical problems, a left carotid endarterectomy was performed. At surgery, the left ICA origin appeared to be completely occluded. After removal of an atherosclerotic plaque from the proximal 1 cm of the left ICA, antegrade flow was restored. The patient has remained neurologically stable, and subsequent noninvasive studies have confirmed patency of the left ICA.

Discussion

Clark et al. [7] were the first to point out that severe narrowing of the ICA may have the angiographic appearance of complete occlusion. They emphasized the importance of visualizing a tapered, rather than a blunted, ICA stump and identifying a small thread of contrast medium corresponding to the course of the ICA in making the correct radiographic interpretation. Lippman et al. [8] and later Houser et al. [9] (from the same group of researchers) showed that an ICA may be diffusely narrowed beyond a high-grade stenosis. They attributed this "poststenotic carotid slim sign" to a partial collapse of the artery due to a greatly decreased perfusion pressure. However, their illustrations suggest that some of the apparent narrowing was rather the result of contrast layering. Kilgore and Fields [10] also showed an example of layering of contrast medium distal to a severe ICA stenosis, which produced a false appearance of a narrow arterial lumen.

Recently, Countee and Vijayanathan [11], Sekhar et al. [12], and Gabrielsen et al. [13] each presented a series of patients with detailed angiographic evaluation of extreme ICA stenosis. Nearly all of the patients had similar angiographic findings, namely, (1) suggestion of complete occlusion of the proximal ICA on early films; (2) collateral flow from external carotid artery branches to the cavernous, and perhaps petrous, segments of the ICA on early films; and (3) a thin trickle of contrast medium producing opacification of the cervical segment of the ICA on late images. All of these authors emphasized the importance of an awareness of this condition and stressed the need for selective common carotid artery injection, using prolonged serial imaging with careful inspection of late films and the use of subtraction. Countee and Vijayanathan [11] recommended a prolonged selective injection technique using a larger than normal volume of contrast medium delivered at a slower rate. In several of the reported cases, the stenosis was so tight that the vessel appeared to be completely occluded at operation [11, 12], as in two of our cases. All of these investigators pointed out that an incorrect angiographic diagnosis of an ICA occlusion could lead to improper patient management.

Blood flow in most of the major arteries of the body tends to be laminar. Fox and Hugh [14] showed experimentally that even with strong turbulent mixing at the site of injection, contrast medium and blood separate quickly if the flow in the injected vessel is slow. They believed that the greater the difference in specific gravity between the contrast medium and blood and the slower the flow, the greater would be the tendency toward layering. If the main stream is already slow, the flow of contrast medium will be even slower, since it will layer along the dependent vessel wall, where laminar flow is slowest. If the vessel is sloped upward, the contrast medium may even start to flow downhill against the main stream. The latter phenomenon may explain the extremely slow antegrade flow and sometimes incomplete opacification of the ICA beyond a very tight stenosis, even with a selective common carotid injection and a prolonged filming sequence [11, 13]. Gabrielsen et al. [13] postulated that occasional retrograde opacification of the precavernous ICA from the cavernous segment, which filled early from external carotid artery collaterals, was probably a gravitational effect, allowing retrograde flow of the dense contrast medium against the extremely slow antegrade blood flow.

The stringlike angiographic appearance of the nearly occluded ICA during selective common carotid angiography is believed to be produced by a combination of luminal collapse secondary to decreased perfusion pressure and layering of the heavy contrast material along the dependent posterior wall [12, 13]. Occasionally, a nonadherent tailing thrombus extending from the preocclusive atherosclerotic plaque may contribute to the carotid "string" sign [13, 15]. The layering phenomenon explains why a horizontal-beam lateral projection is usually most valuable for demonstration of the nearly occluded ICA when selective common carotid angiography is performed.

Sekhar et al. [12] considered the likelihood of misdiagnosis of complete ICA occlusion to be much greater with arch

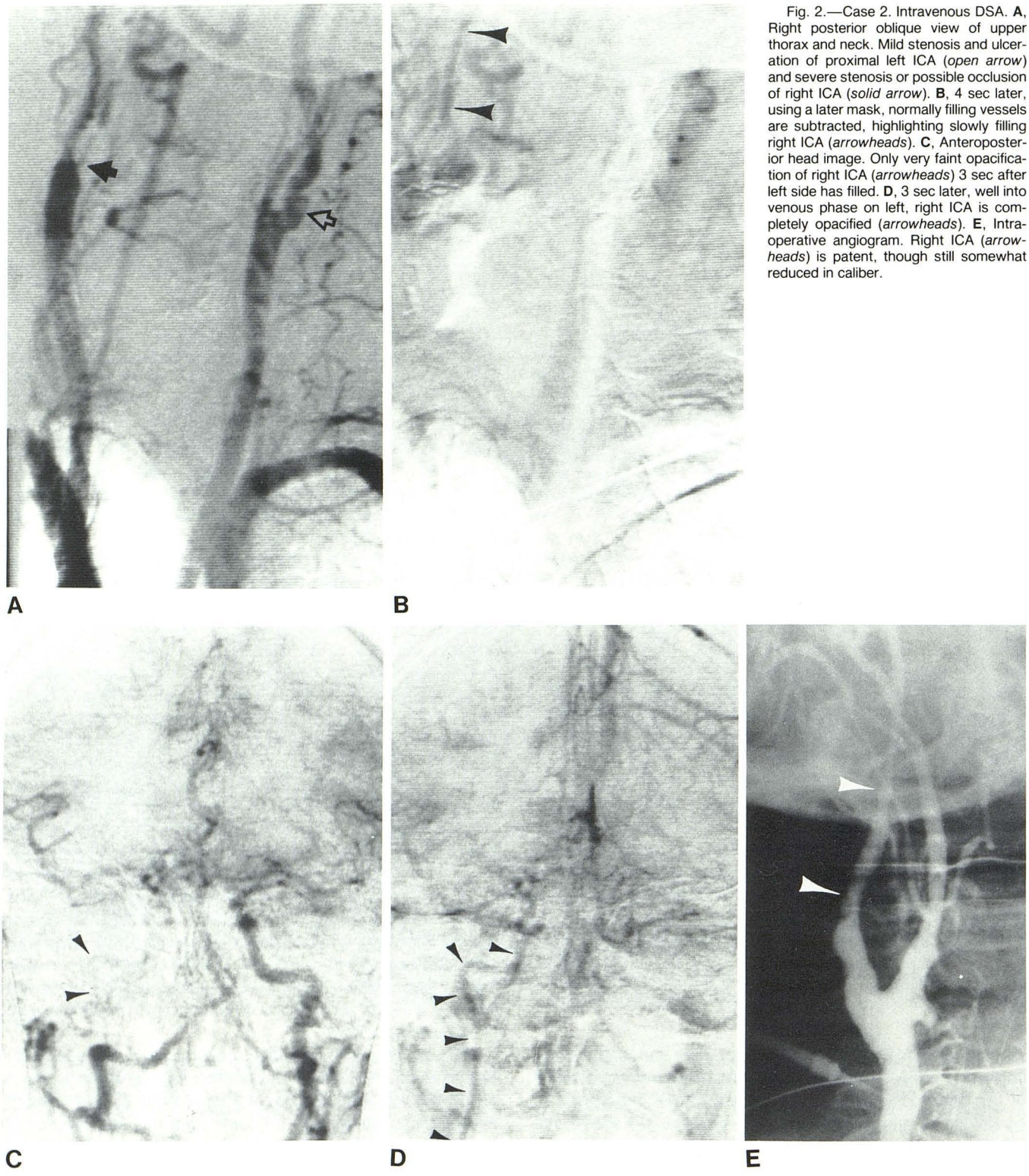

Fig. 2.—Case 2. Intravenous DSA. **A**, Right posterior oblique view of upper thorax and neck. Mild stenosis and ulceration of proximal left ICA (*open arrow*) and severe stenosis or possible occlusion of right ICA (*solid arrow*). **B**, 4 sec later, using a later mask, normally filling vessels are subtracted, highlighting slowly filling right ICA (*arrowheads*). **C**, Anteroposterior head image. Only very faint opacification of right ICA (*arrowheads*) 3 sec after left side has filled. **D**, 3 sec later, well into venous phase on left, right ICA is completely opacified (*arrowheads*). **E**, Intraoperative angiogram. Right ICA (*arrowheads*) is patent, though still somewhat reduced in caliber.

aortography than with selective, distal common carotid artery injection. One might conclude, therefore, that DSA of the carotid arteries, which uses an intravenous rather than intraarterial injection, would be a low-yield procedure for demonstrating the nearly occluded ICA. This has not been our experience, however. First, the availability of immediate subtraction during the examination facilitates the identification of contrast medium, especially in areas of overlying bony structures. In

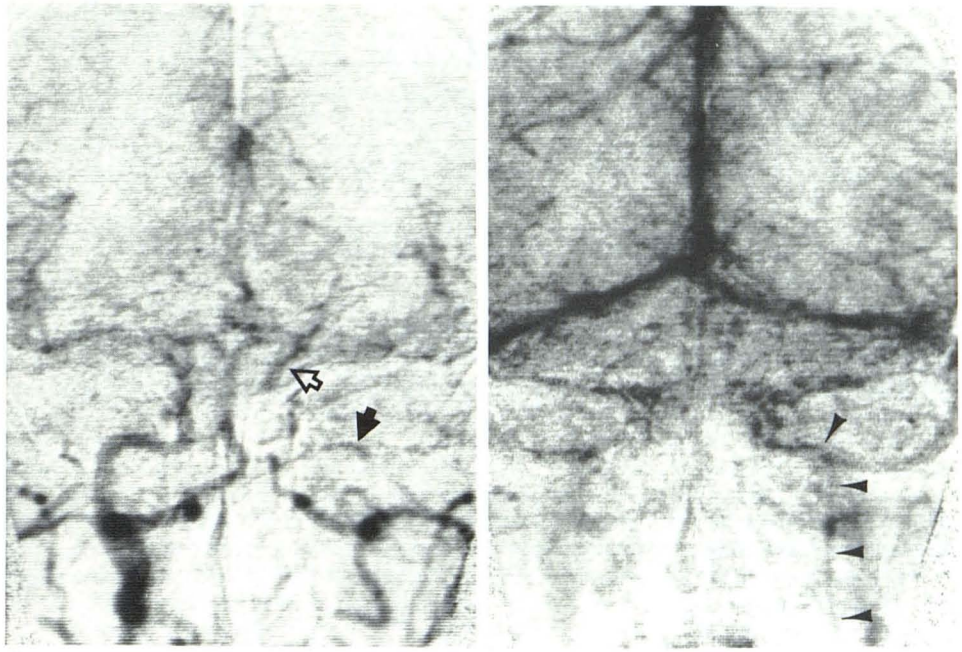

Fig. 3.—Case 3. Intravenous DSA. **A**, Arterial phase. Only supraclinoid segment (*open arrow*) and petrous segment (*solid arrow*) of left ICA opacify, probably via external carotid collaterals. **B**, Venous phase, using a slightly later mask to remove residual opacification of vertebral arteries. Small but patent left ICA (*arrowheads*).

addition, the ability to use rapidly any of the serial images as a mask often allows correction of motion artifacts and occasionally permits subtraction of arteries that fill in a normal time sequence from one that fills slowly, making the latter vessel conspicuous (figs. 2B and 3B). Second, the capability of computer enhancement permits the use of dilute intravascular contrast medium, which would be too faint to be seen with standard film-screen studies. Third, anteroposterior head projection allows immediate comparison with the contralateral ICA, which is helpful for rapid anatomic localization of the high cervical and petrosal segments of the slowly filling vessel and also provides useful information about comparative flow dynamics [6].

However, the greatest benefit of the intravenous technique may be the thorough mixing of the contrast medium with blood, which occurs in the heart, the pulmonary circulation, and again in the heart and ascending aorta before reaching the carotid arteries. Mixing and dilution of the contrast medium minimizes any tendency toward layering beyond an area of severe stenosis [14]. The contrast medium thus not only will reflect the true rate of blood flow beyond the stenosis but also will define the true size of the lumen. The stenotic vessel therefore should opacify more rapidly and more completely with an intravenous than with a common carotid artery injection, and horizontal-beam imaging should not be necessary, since layering does not occur.

We do not wish to conclude, on the basis of these three cases, that intravenous angiography is superior to conventional angiography in diagnosing the nearly occluded ICA. Intravenous DSA has several disadvantages when compared with transarterial techniques, including lack of selectivity, vessel overlap, lower spatial resolution, and the need for patient cooperation to obtain successful subtraction. However, in our experience, over 90% of intravenous cervicocerebral studies have been of good or excellent quality. With intravenous DSA, evaluation of an apparently occluded ICA for patency is generally a simple and relatively quick procedure, using multiple subtraction views from various phases of the injection. With conventional techniques, on the other hand, subtraction is much more time-consuming and usually must be done after the examination is terminated.

In all three of our cases, the anteroposterior projection of the head and upper neck was most valuable in diagnosing a nearly occluded ICA, by providing a side-by-side comparison with the contralateral ICA. In one patient (case 3), early opacification of the petrous segment by collaterals provided a clue that the more proximal cervical segment might opacify on later images. Close examination of the common carotid artery bifurcation regions in the three patients suggested that the length of the stenotic segment was equal to the distance between the apparent residual stump of the ICA origin and the lowest level at which the collapsed ICA lumen was visualized (fig. 1D).

If the question of ICA patency cannot be resolved with an intravenous digital study, the artery of interest can be evaluated by selective arterial catheterization. This also can be done with the digital system in order to take advantage of the immediate subtraction capability and the need for much lower doses of contrast medium than with conventional techniques. So far, however, we have not found it necessary to confirm the intravenous diagnosis of a nearly occluded carotid artery with selective catheterization. We conclude that a nearly occluded internal carotid artery can at times be diagnosed safely and reliably with intravenous DSA.

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