Limitations of noninvasive testing in assessing the "occluded" carotid artery.

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Limitations of Noninvasive Testing in Assessing the "Occluded" Carotid Artery

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Over a 3 year period eight cases of atherosclerotic pseudoocclusion were detected by carotid angiography. The diagnosis was based on the detection of a thin, delayed antegrade trickle of contrast medium distal to an area of extreme stenosis. In six of these cases both direct and indirect noninvasive tests were interpreted as showing total occlusion. In one case these tests were thought to demonstrate a normal bifurcation, and only once were they successful in suggesting the diagnosis of high-grade stenosis. Five of these eight patients subsequently underwent carotid endarterectomy. Patients who present with appropriate clinical indications for carotid endarterectomy should undergo angiography even when the noninvasive tests indicate a total occlusion of the internal carotid artery. In such circumstances the angiographic technique should be altered specifically to detect the possible presence of atheromatous pseudoocclusion.

Radiologists have long recognized that highly stenotic but still patent internal carotid arteries may be falsely diagnosed as occluded by contrast angiography unless great care is taken in performing and interpreting the study [1, 2]. Terms such as atheromatous pseudoocclusion, the string sign, the poststenotic carotid slim sign, and the nearly occluded carotid artery have been used to describe the situation in which flow distal to a high-grade stenosis is so minimal and so delayed that it is easily overlooked [3–7]. The clinical importance of distinguishing between the truly occluded and nearly occluded carotid artery is that patients presenting with the latter may well be candidates for prompt endarterectomy [3, 8–11].

In the past 3 years we have seen eight such cases. These patients were all studied by a variety of noninvasive techniques before angiography. In only one instance did the noninvasive tests suggest the presence of a high-grade stenosis. Of the other seven cases, six were interpreted as showing complete occlusion and one was thought to demonstrate a normal carotid bifurcation.

The inability of the older indirect noninvasive techniques to distinguish between severe stenosis and total occlusion has long been recognized [12–14]. The limitations of the newer and increasingly sophisticated direct Doppler flow studies and high-resolution B-scan imaging in this clinical setting have not been emphasized. Individuals who present with appropriate clinical indications for possible carotid endarterectomy should undergo angiography even when the noninvasive tests indicate a total occlusion of the internal carotid artery. In such instances, the angiographic technique should be altered specifically to detect the possible presence of an atheromatous pseudoocclusion.

Materials and Methods

All patients in this study were examined with a 4 MHz continuous-wave direct Doppler imaging device that provides a color-coded flow map at the level of the carotid bifurcation [15, 16]. This instrument uses a single transducer with two crystals, one to transmit a constant signal of known frequency and the other to sample the reflected Doppler signal. Any shift in frequency of the returning signal relative to the transmitted signal is proportional to the velocity of the moving erythrocytes within that part of the vessel sampled. In the system employed in this study, the peak frequency at a given point is identified and displayed as a color-coded dot on a monitor screen. The frequency shifts are in the audible range and thus can be monitored aurally and mechanically. In addition, the reflected signal can be fed into a spectrum analyzer for more sophisticated analysis. With increasing degrees of stenosis, there is an increase in the velocity of red blood cells across the area of narrowing and a corresponding increase in the detected peak frequency shift [17]. Turbulence at and distal to the site of stenosis can also be appreciated. The absence of any frequency shift in the returning Doppler signal is interpreted as suggesting a total occlusion.

Real-time high-resolution B-mode imaging devices can be coupled with pulsed Doppler sonographic equipment to permit evaluation of blood flow in a discrete sample volume within a visualized vessel [18, 19] (fig. 1). Three such units, termed duplex scanners, are used in our laboratory. The diagnosis of vascular occlusion is suggested by the absence of any frequency shift in the returning Doppler signal when the sample volume is placed within an artery. The real-time sonographic image itself may provide strong clues to the diagnosis of a severely diseased or totally occluded internal carotid artery. The acoustic impedance of intraluminal thrombus may be identical to that of flowing blood. Therefore, a normal and an occluded vessel may have an identical appearance. In patent arteries, the vessel wall expands and contracts transversely during systole and diastole. With complete occlusion, this motion often ceases, and the artery may instead pulse longitudinally. This presumably represents a transmission of the arterial pressure wave striking against the occluded stump. Such movement of the vessel may also be seen with highly stenotic but still patent internal carotid arteries.

Velocity waveform tracings were recorded with both pulsed and continuous-wave Doppler from the common carotid artery. Because resistance to blood flow in the brain is low, flow in the common and internal carotid arteries is normally antegrade throughout the entire cardiac cycle. With high-grade stenosis or occlusion, peripheral resistance is markedly increased and diastolic flow may then fall to

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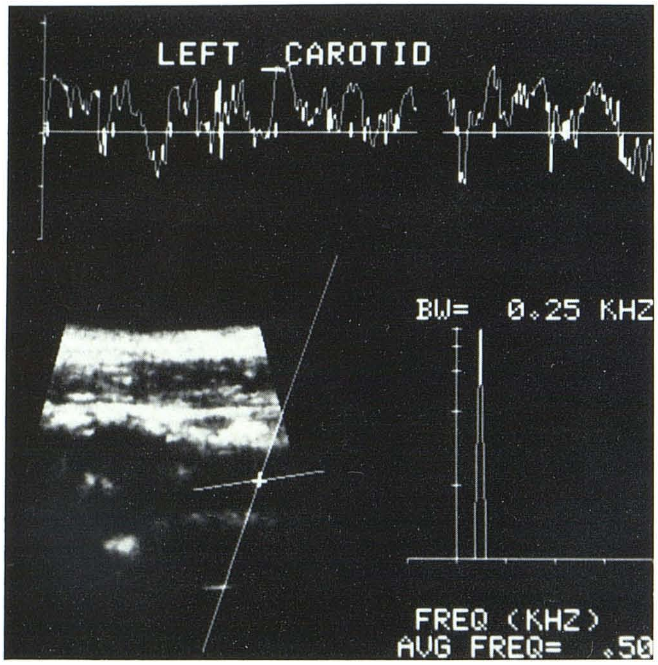

Fig. 1.—Sagittal view of left carotid bifurcation. Sample volume has been placed in center of common carotid artery just proximal to bulb. Carotid waveforms are depicted along top line.

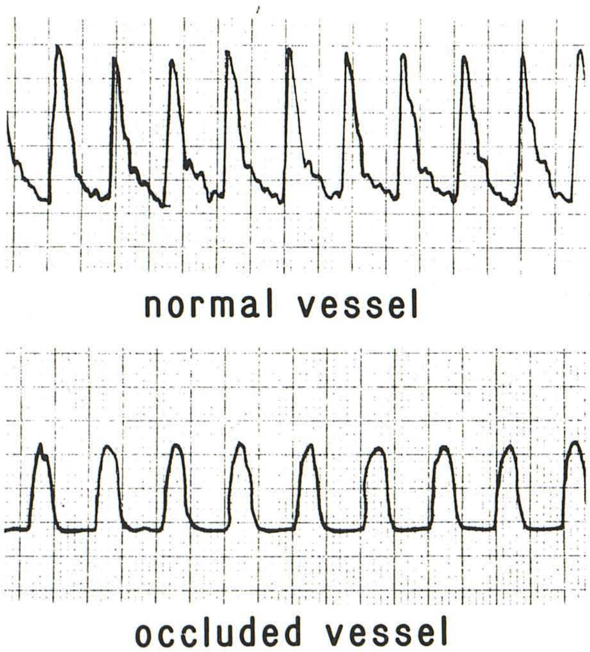

Fig. 2.—Common carotid waveforms. Upper tracing is velocity pattern of normal common carotid artery; flow is always antegrade. Lower tracing is velocity tracing from common carotid artery with occlusion of internal carotid artery. Note there is no flow during diastole.

zero or even reverse. Thus, analysis of the velocity waveform may help in the diagnosis of carotid occlusion [20, 21] (fig. 2).

Both periorbital directional Doppler sonography and oculoplethysmography are indirect monitors of carotid artery hemodynamics [22]. Periorbital Doppler studies were carried out using a 10 MHz continuous wave Doppler to determine the direction of flow in the supratrochlear and supraorbital arteries. The test was considered positive for significant carotid disease if there was reversal of flow into the orbit in a resting state or obliteration of flow with compression of the ipsilateral preauricular, facial angular, or bridge arteries [23]. Oculoplethysmographic tracings were interpreted as positive for significant disease when there was a marked delay in the arrival of either ocular pulse [24]. Neither of these tests is able to distinguish between varying degrees of high-grade stenosis, although the presence of a strongly positive oculoplethysmographic study without a detectable ipsilateral bruit was interpreted as suggesting the possibility of occlusion.

The eight cases of pseudoocclusion were drawn from a total of 343 patients who underwent both noninvasive tests and carotid angiography. All 343 patients had direct Doppler imaging and at least one of the two indirect tests performed. In addition, duplex studies were done on all individuals suspected of having an occluded vessel. Employing the Seldinger technique, angiography was carried out by selectively catheterizing both common carotid arteries.

In all instances where we considered the diagnosis of carotid occlusion, either on the basis of the noninvasive results or because of observations made at the time of angiography, an angiographic technique first suggested by Countee and Vijayanathan [11] was employed in order to minimize the chances of a pseudoocclusion being missed. As described by them, a catheter was placed close to the carotid bifurcation and 16 ml of Conray 60 was injected at a rate of 4 ml/sec for 4 sec. With stenosis or occlusion most of the contrast medium is delivered to the external carotid circulation and is painful for the patient, so normally only a single injection was performed. Filming was done in the lateral projection with coning to include the supraclinoid carotid artery as well as the carotid bifurcation. In order to insure that any evidence of persistent antegrade flow in a severely stenotic internal carotid artery was not missed, one film/sec was taken for 14 sec (figs. 3–5).

Results

In a review of 343 consecutive angiograms, eight studies were categorized as representing atheromatous pseudoocclusion. In only one of these eight cases did the noninvasive tests suggest the diagnosis of high-grade stenosis. Of the other seven, the noninvasive tests were interpreted as showing complete occlusion in six instances and were falsely interpreted as being normal once. This last patient did not have a duplex study. Five of the patients presented with a history of acute transient ischemic attacks; two presented with mild strokes that had cleared completely; and one was asymptomatic except for the presence of bruits. Five of these eight patients subsequently underwent carotid endarterectomy.

Discussion

There are several possible explanations for our inability to distinguish between very high degrees of stenosis and complete occlusion by noninvasive tests. The mean linear flow velocity for red blood cells in the carotid artery is about 500 mm/sec [25]. As the lumen is narrowed by plaque, blood flow must accelerate across the area of narrowing if a constant flow to the brain is to be maintained.

With very high degrees of stenosis, constant flow to the brain may fall. As emphasized by Zwiebel and Crummy [26], the diagnosis of occlusion is dependent on the failure to detect a returning Doppler shift, and thus is inferred from negative information. The potential for error in such a situation is greater than when interpreting positive data.

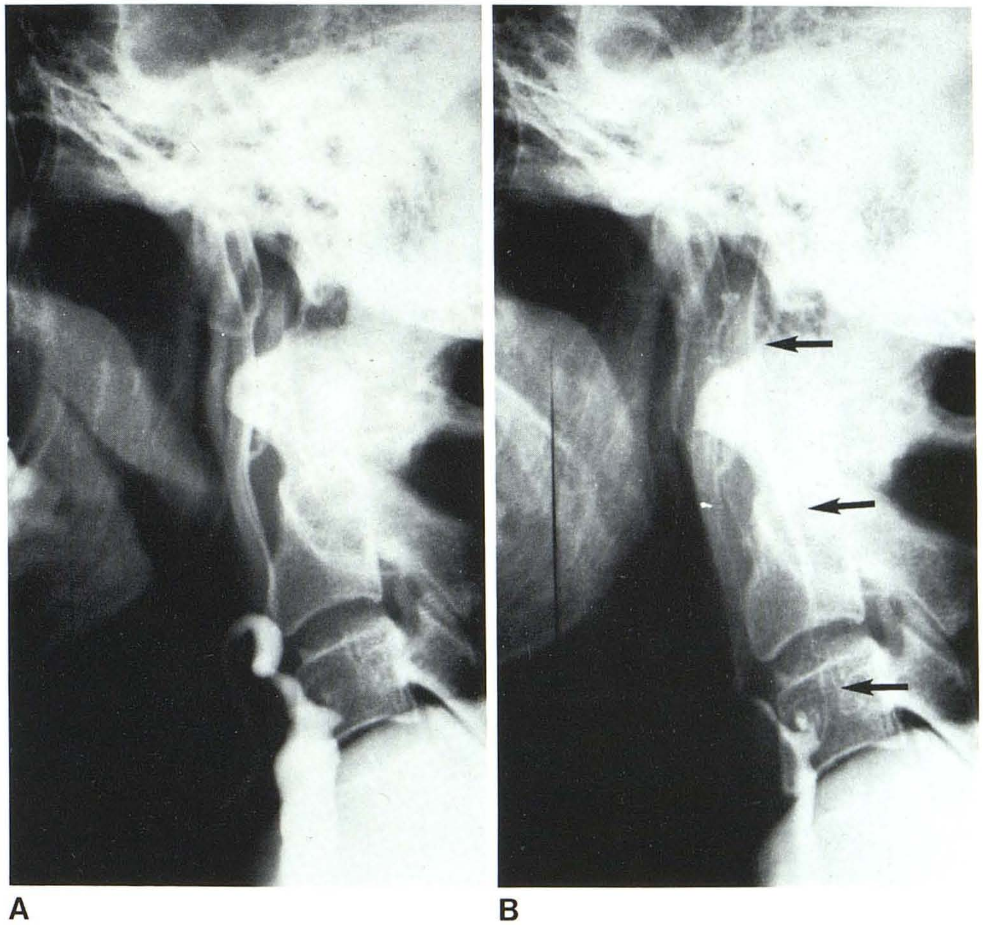

Fig. 3.—Right common carotid angiograms, lateral view, coned to include both bifurcation and supraclinoid carotid. **A**, Image at 1 sec suggests that internal carotid artery is totally occluded, but image at 9 sec (**B**) demonstrates thin trickle of contrast (*arrows*) progressing cephalad to base of skull.

Blood velocities distal to high-grade stenosis, where blood flow has decreased dramatically, may well fall below the level that can be detected by standard Doppler techniques. The largest specular reflector investigated during the Doppler examination of the carotid artery is in fact the vessel itself. It is a large object that moves during systole and diastole, generating energy and sending a large signal back to the transducer head. This phenomenon is termed wall thump. To eliminate this, Doppler units contain a high-pass filter that discriminates against low-frequency signals. This may in turn make it impossible to detect markedly slow blood flow.

Also, as the number of red blood cells passing beyond the point of stenosis is reduced, the number of moving reflectors may be so few as to generate such a weak reflected signal that it falls below the system's threshold of sensitivity. Even if a high-frequency flow jet is maintained in very tight stenoses, this latter problem might preclude its detection.

The diagnosis of pseudoocclusion was made in about 2% of our patients. This figure may seem rather high and might suggest too broad a definition of pseudoocclusion. In seven other cases the noninvasive tests suggested total occlusion where a severe degree of stenosis was detected by angiography. These patients were not categorized as having atheromatous pseudoocclusion because they failed to meet the angiographic criteria for this diagnosis. The most important reason for the rather large number in this series is probably our aggressive search for this entity. We also believe that using the angiographic technique suggested by Countee and Vijayanathan [11] was the crucial factor in permitting us to make the diagnosis.

Intravenous digital subtraction angiography may well misdiagnose pseudoocclusion as complete occlusion due to the inherent limitations in resolution of this technique compared with standard angiography. Our most recent patient underwent digital subtraction angiography 2 days before standard angiography. The diagnosis by the first procedure was that of complete occlusion, whereas with conventional angiography a delayed trickle of contrast material was visualized in the internal carotid artery. This patient then underwent carotid endarterectomy.

We have found that noninvasive techniques may not always distinguish between very high degrees of stenosis and complete occlusion. Therefore, the diagnosis of occlusion by noninvasive testing should not preclude angiography, especially in patients who present with transient ischemic attack. Such patients should undergo selective carotid angiography rather than venous injection digital subtraction arteriography. The angiographic technique should be altered specifically to improve the possibility of detecting atheromatous pseudoocclusion of the internal carotid artery.

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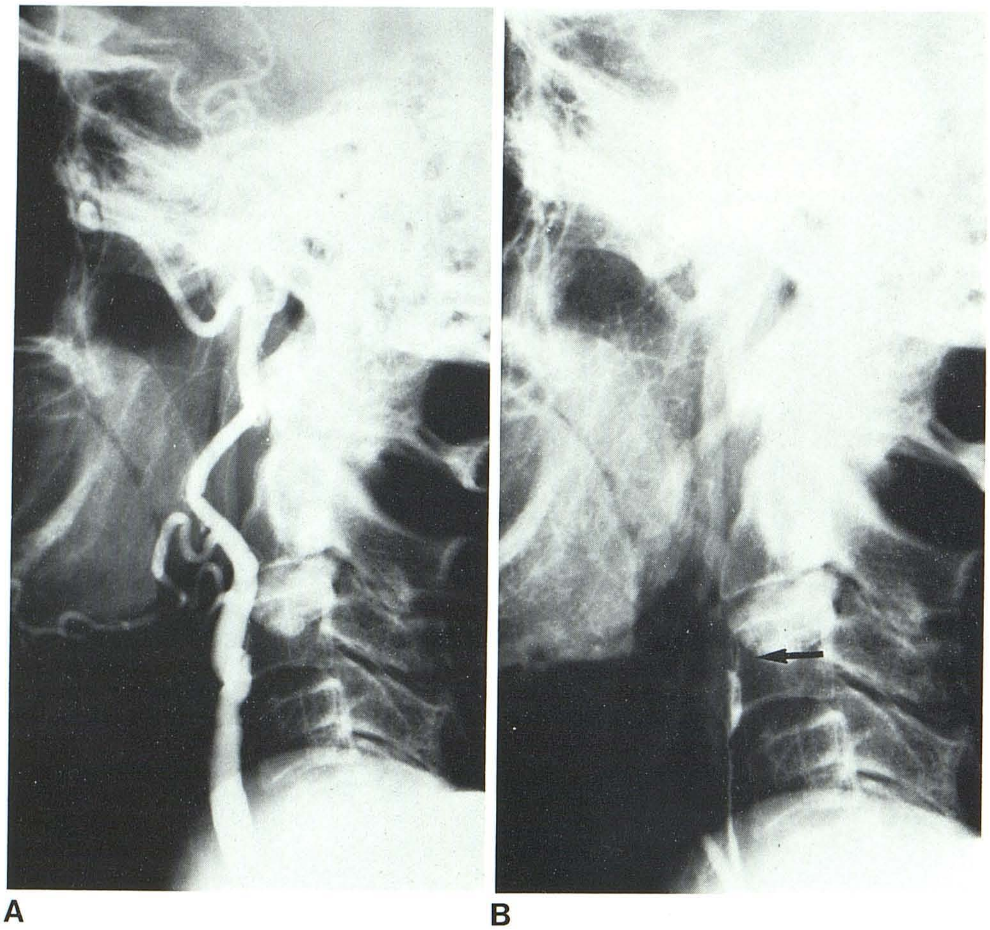

Fig. 4.—Left common carotid angiograms. **A**, Image at 2 sec shows no flow in internal carotid. **B**, After injection of 16 ml Conray 60 at 4 ml/sec there is progression of contrast material to level of C2–C3 at 6 sec (*arrow*). Contrast did not reach base of skull.

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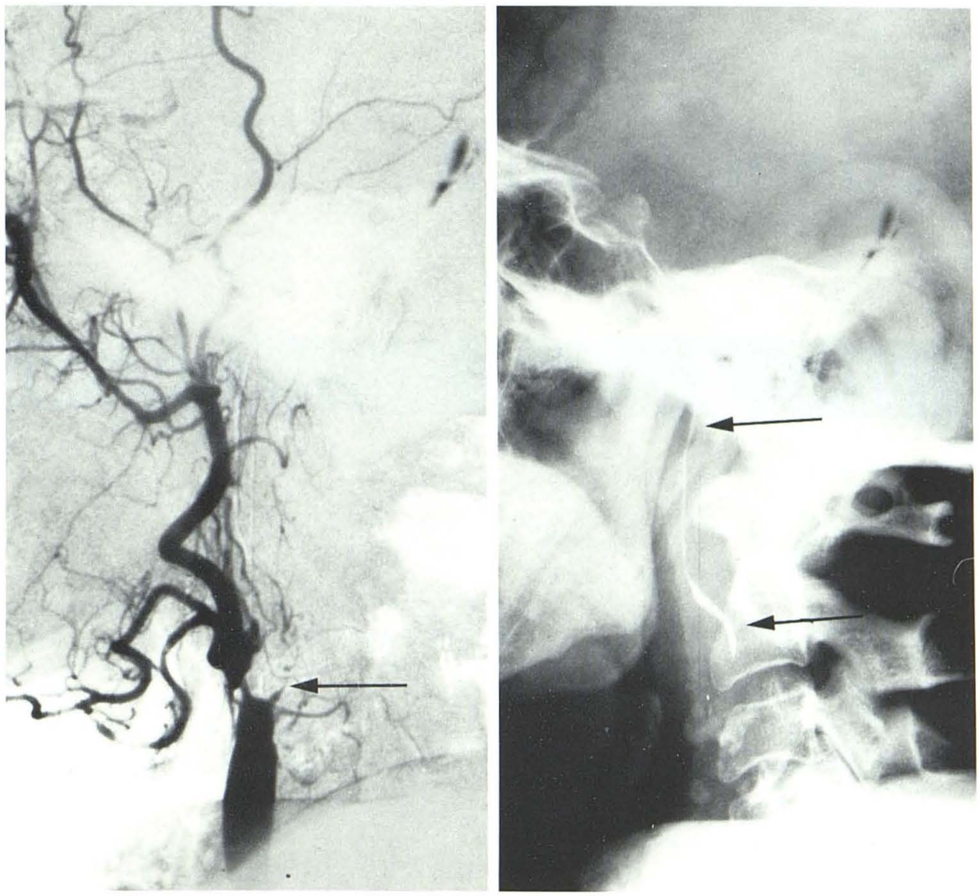

A B

Fig. 5.—Right common carotid angiograms, lateral view. **A**, At 3 sec. Only a hint of antegrade flow of contrast in proximal internal carotid artery (*arrow*). **B**, At 30 sec after contrast injection. No appreciable washout of material (*arrows*).

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