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CT with Image Reformation for Noninvasive Screening of the Carotid Bifurcation:
Early Experience

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Twenty-two cervical carotid artery bifurcations were evaluated in 11 patients using a high-resolution computed tomographic (CT) technique with image reformation permitting display of the bifurcation anatomy. Arteriography was also done in eight of the patients, two of whom subsequently underwent carotid endarterectomy. The CT study showed patency of the proximal internal carotid artery in every case and depicted significant stenosis of four vessels. Thrombus within a large ulcer was seen in one vessel on CT, but another shallow ulcer found on angiography was missed. Although the data are limited, this preliminary experience suggests a possible role for this technique in carotid bifurcation screening and indicates further investigation may be worthwhile.

The known association of carotid bifurcation atheroma with transient or permanent ischemic brain insult has prompted an aggressive diagnostic and therapeutic approach to this lesion in certain high-risk patient groups. The small but finite risk of complications during angiography hinders the use of this invasive diagnostic method for large segments of the population at risk. For this reason, the past decade has seen a marked proliferation of technology aimed at noninvasive evaluation of the carotid bifurcation. The most widely used tools for this purpose include carotid phonoangiography and oculoplethysmography [1–4] and various forms of Doppler flow analysis [5–7]. The last method has recently been coupled to real-time sonographic imaging of the carotid bifurcation [7, 8]. Most recently, digital image-processing innovations and high-resolution fluoroscopic equipment have allowed display of arterial structures after intravenous injection of contrast material and electronic image subtraction [9–11].

All these techniques have inherent limitations [11–14] and require the purchase of additional and, in some cases, quite expensive equipment. For this reason, we examined the potential of our third generation computed tomographic (CT) scanner in evaluating the carotid bifurcation in patients referred for brain CT.

Subjects and Methods

Eleven patients were studied: seven had a CT cervical carotid evaluation as an adjunct to routine contrast-enhanced brain CT on a GE 8800 scanner. Indications included suspected ischemic neurologic deficits in six patients and the differentiation between an ischemic deficit and a brain metastasis in one patient with a primary bladder carcinoma who also had a carotid bruit. Five of these patients also had carotid angiography. Three other patients scheduled for aortic surgery had carotid bruits and the vessels were evaluated with CT and angiography. A final patient had the carotid arteries assessed on a neck CT scan to evaluate a nasopharyngeal neoplasm.

Each patient had 1.5 mm, thin, contiguous axial slices taken in a dynamic sequence from the mid C2 through the C5 vertebral level before routine brain sections were obtained. Contrast material injection into an antecubital vein was done via a 75 ml bolus injection followed by a 75 ml drip infusion of meglumine iothalamate 60%. The dynamic sequence

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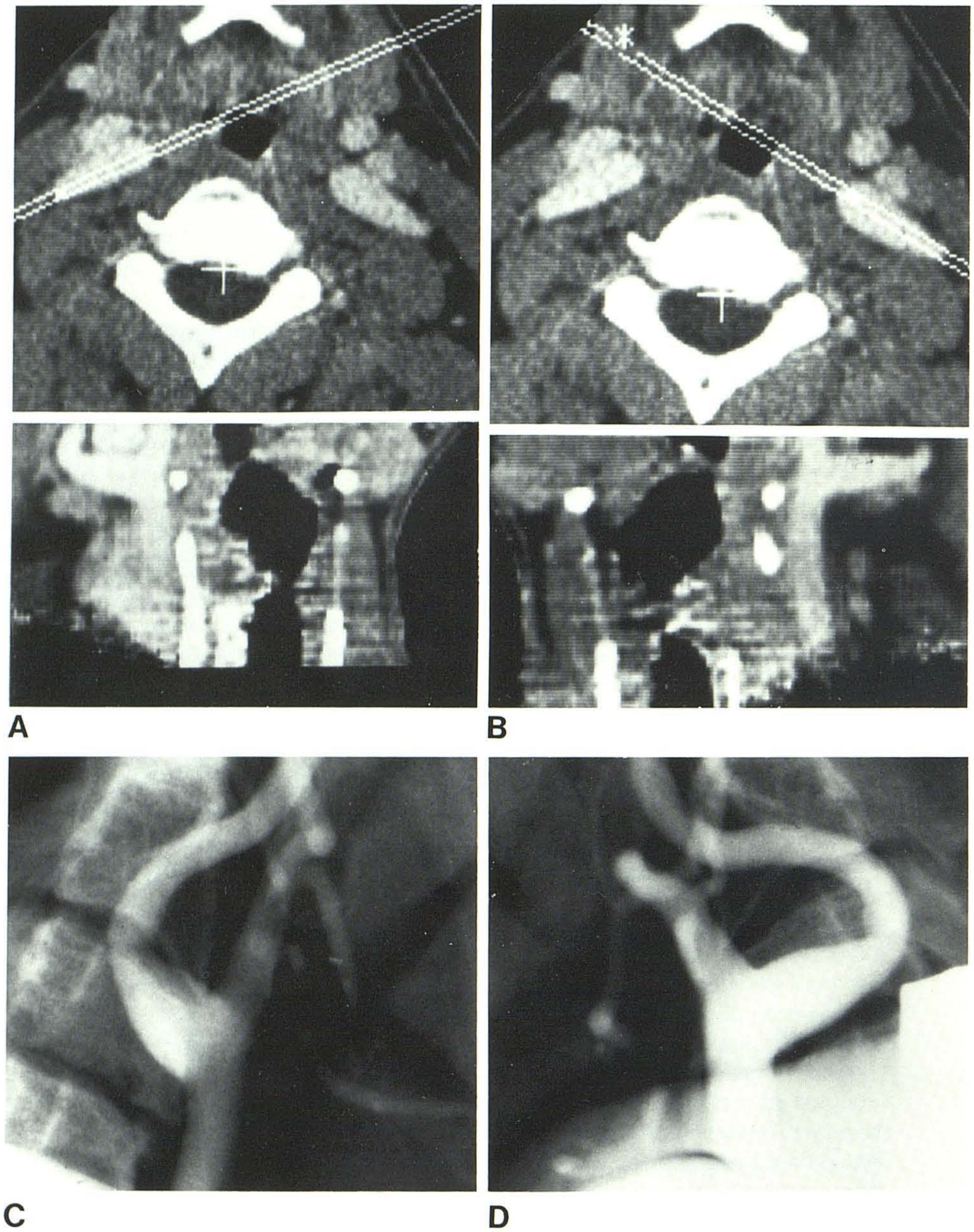


Fig. 1.—54-year-old man with bilateral parietal infarcts. **A** and **B**, Anterior oblique reformations through both carotid bifurcations. Ectatic, tortuous proximal internal carotids, but no focal lesion. **C** and **D**, Common carotid arteriogram verified findings bilaterally.

(Dynapak, GE software package) in the neck used a 9.6 sec scan time at 160 mAs, permitting about 1 sec interscan intervals. Automatic table incrementation allowed the entire neck sequence (up to 45 slices) to be done in less than 10 min. We routinely obtained at least 35 slices to ensure that enough of the artery was scanned to include the carotid bifurcation. Total radiation dosage using the low mAs as dictated by the dynamic technique is less than 2 rad (0.02 Gy). A 9.6 sec scan time was used as the mAs factors are already at the lower threshold of photon influx needed for adequate resolution. Shorter scan times are available but limit photon flux further. Shorter scan times are still too slow to counteract the effects of vessel pulsation (see below).

After the routine brain study, axial sections were used to orient paraaxial image reformation (Arrange, GE software package) in a plane that best displayed the carotid bifurcation. A trained radiologist needs about 2–3 min to generate an image reformation. Several attempts were needed to optimally evaluate the carotid artery in many cases, since the vessels wandered in and out of the plane of reformation. Overall, no more than 30 min of interaction with the console was necessary to produce the desired images.

Eight patients also underwent cerebral angiography. Three had significant carotid lesions. Two had a history of recent transient ischemic attacks and were treated with carotid endarterectomy. The findings of the CT study, angiography, and endarterectomy were compared.

Results

Our 11 patients provided 22 carotid bifurcations for evaluation on CT; 15 of these vessels were also studied with angiography (one of eight angiogrammed patients had, for technical reasons, only a single arteriogram).

Four patients had no focal stenosis in either cervical

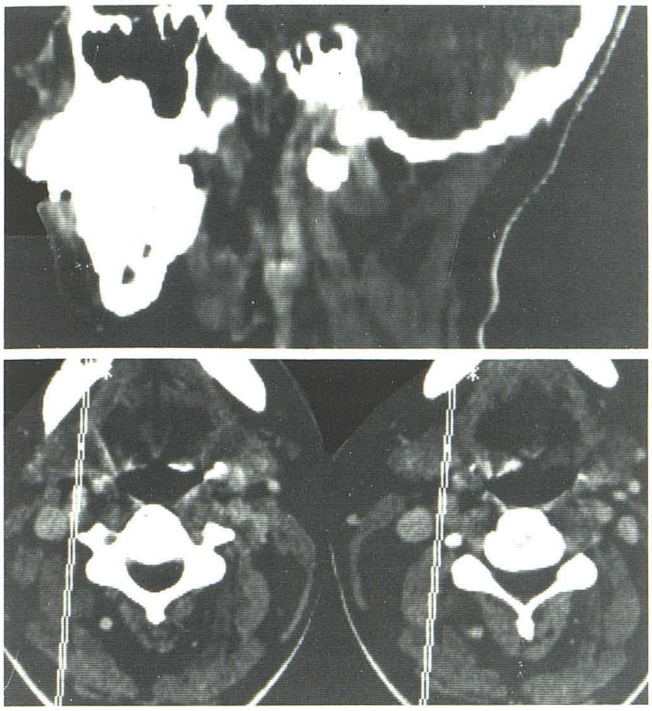


Fig. 2.—78-year-old man with nasopharyngeal carcinoma. Right carotid sagittal reformation. Normal bifurcation and vessel patency up to temporal bone.

carotid vessel on angiography or on CT (figs. 1 and 2). Three other patients had normal vessels on CT alone. In one of these three patients the CT study was suboptimal, but his clinical status precluded surgical therapy or angiography. The other two patients had adequate CT studies. One is shown in figure 2 (his carotid arteries were studied incidentally on a dynamic CT scan to evaluate a nasopharyngeal neoplasm); the other patient's advanced age (80) and limited symptoms did not justify an aggressive approach.

In two of these seven patients just described, CT images were severely degraded by swallowing and/or a high-density streak artifact off the mandible. Patency of the internal carotid artery could be documented despite these technical problems in both, but definitive statements regarding focal stenosis and ulceration were not possible. This led us to modify our technique by extending the patient's neck and/or angling the scanner gantry so that the axial sections in the higher cervical region cleared the mandibular bone anteriorly whenever possible. This, in conjunction with careful instructions to the patient regarding swallowing only between scans, improved the quality of the images in the remaining patients.

Proximal internal carotid stenosis was seen bilaterally in two other patients on both the CT and angiographic images; subsequent endarterectomy verified severe atheromatous disease bilaterally in one (fig. 3). The second patient exhibited striking calcific plaques in the proximal narrowed internal carotids (fig. 4). Angiography verified the occlusive disease; however, decision regarding prophylactic endarterectomy before repairing his calcific aortic valve had not been reached at the time of this writing.

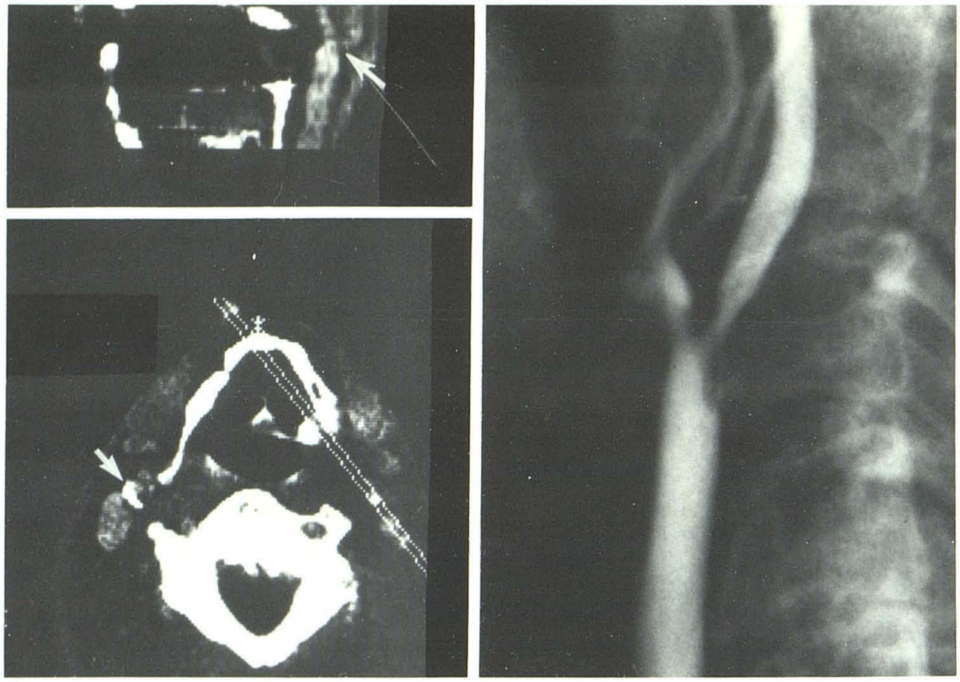
One other patient exhibited bilateral ulceration on his carotid arteriogram. The CT study on the more obvious side showed calcification, focal expansion of the vessel lumen, and a thrombus on the axial views, seen on the reformatted image as a punctate filling defect. Endarterectomy demonstrated a deep ulceration and thrombus at this site. The contralateral shallow ulcer seen at angiography showed only calcium density in the vessel wall in the CT study, without obvious ulceration (figs. 5 and 6). The last patient studied with both methods had a normal CT and angiogram on the right, whereas the left carotid artery showed a calcified plaque on CT. Angiography verified a mild (about 30%) narrowing at that site; the calcific component was impossible to see.

Discussion

Use of image reformation from dynamic CT scans in the evaluation of carotid disease has been suggested by others [15]. Our preliminary experience suggests that high-resolution CT scanning with image reformation can provide diagnostic information regarding the status of the carotid bifurcation. The technique has obvious inherent limitations; however, several unique advantages make further investigation of its clinical applicability worthwhile.

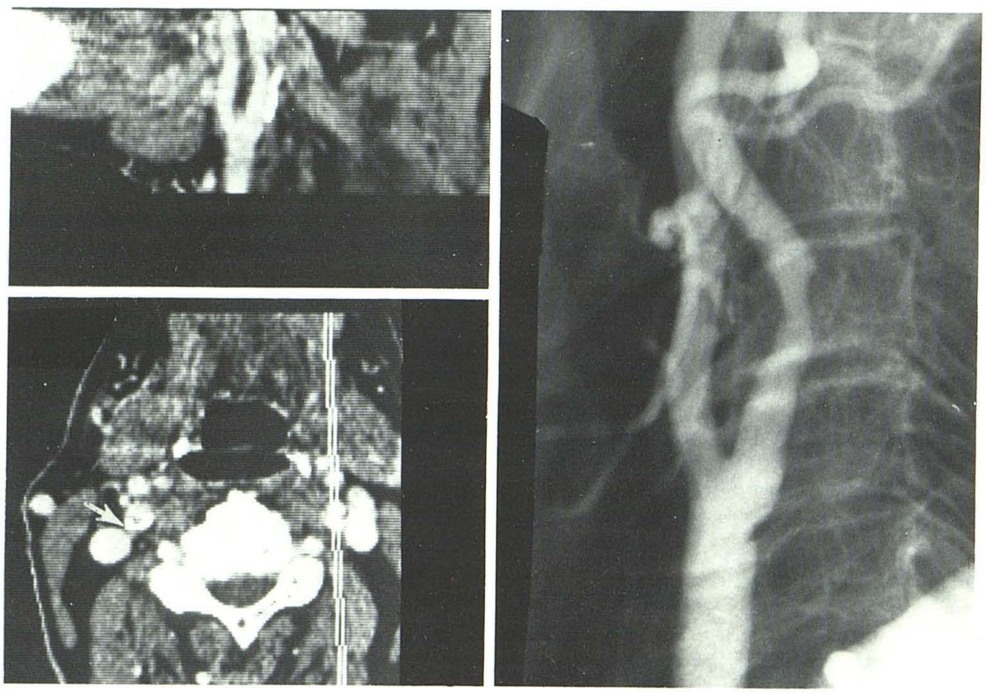
First, the neck study can be performed in conjunction with the single-contrast injection necessary for an already requested contrast-enhanced brain CT scan and requires only 10 min of extra scanning time. Second, image reformation allows display of the carotid bifurcation in the appropriate plane, thus minimizing or eradicating the problem of other vessel superimposition, a problem often encountered in digital intravenous angiography leading to multiple injections of contrast material in different positions with variable results [10, 11]. Third, the exquisite sensitivity of CT to soft-tissue contrast differences enables depiction of vascular structures, and calcification not always seen on plain films, without the necessity of mechanical bolus injections through catheters placed (with fluoroscopic guidance) in central veins. Finally, the CT hardware and software necessary for this study is already in use and is becoming more widely distributed for a variety of applications. Its use for cervical carotid screening could obviate obtaining other expensive technology for a relatively limited application.

The inherent limitations of the technique are significant. The most important is poor temporal resolution. Although patient motion is minimized with the use of dynamic sequence scanning and head restraint in the scanner, vessel pulsation occurs throughout the scan sequence. Such motion during the scan may exaggerate its diameter (fig. 3). Also, pulsation translated over time might "fill in" (but should not overestimate) areas of focal stenosis and make ulceration difficult to detect. However, the latter lesion may be inaccurately evaluated even on angiography in up to 33% of the cases [16, 17]. Our admittedly limited data, and that of others, suggest that calcified plaque [18], significant stenosis, thrombus (a lesion difficult to see with any other method), and total occlusion of the proximal internal carotid [19], are definable on CT despite the limitation imposed by



A B

Fig. 3.—75-year-old man with bilateral carotid bruits. **A**, Left anterior oblique reformation through left carotid bifurcation. Top, severe stenosis at origin of left internal carotid artery (*large arrow*). Jugular vein seen laterally. (Bottom, calcified plaque in right carotid artery, *small arrow*). **B**, Common carotid arteriogram verified lesion.



A B

Fig. 4.—80-year-old man with severe aortic stenosis, dizziness, and bilateral carotid bruits. **A**, Sagittal reformation of left carotid bifurcation. Diffuse calcific plaque with segmental narrowing of proximal internal carotid. Calcific plaque in right internal carotid artery on axial view (bottom, *arrow*). **B**, Corresponding arteriographic frame, segmental disease. Right carotid artery showed similar findings with both methods.

pulsation. Nevertheless, the sensitivity and accuracy of this technique needs to be investigated, preferably in centers that can compare the results with those obtained using already established noninvasive methods.

A second limiting factor shared by other noninvasive methods is the radiologist's time necessary for image reformation, especially since it may be difficult to quickly select the bifurcating carotid artery from multiple vascular structures opacified on the axial scans. A preliminary dynamic sequence of three or four scans at a single level at the C3 region after a 20 ml intravenous bolus injection of contrast material can separate out the arteries from the vein, but requires additional (albeit minimal) time and contrast dosage. However, existing noninvasive methods are at least equally time-consuming.

Finally, the plane of image reformation cannot account for

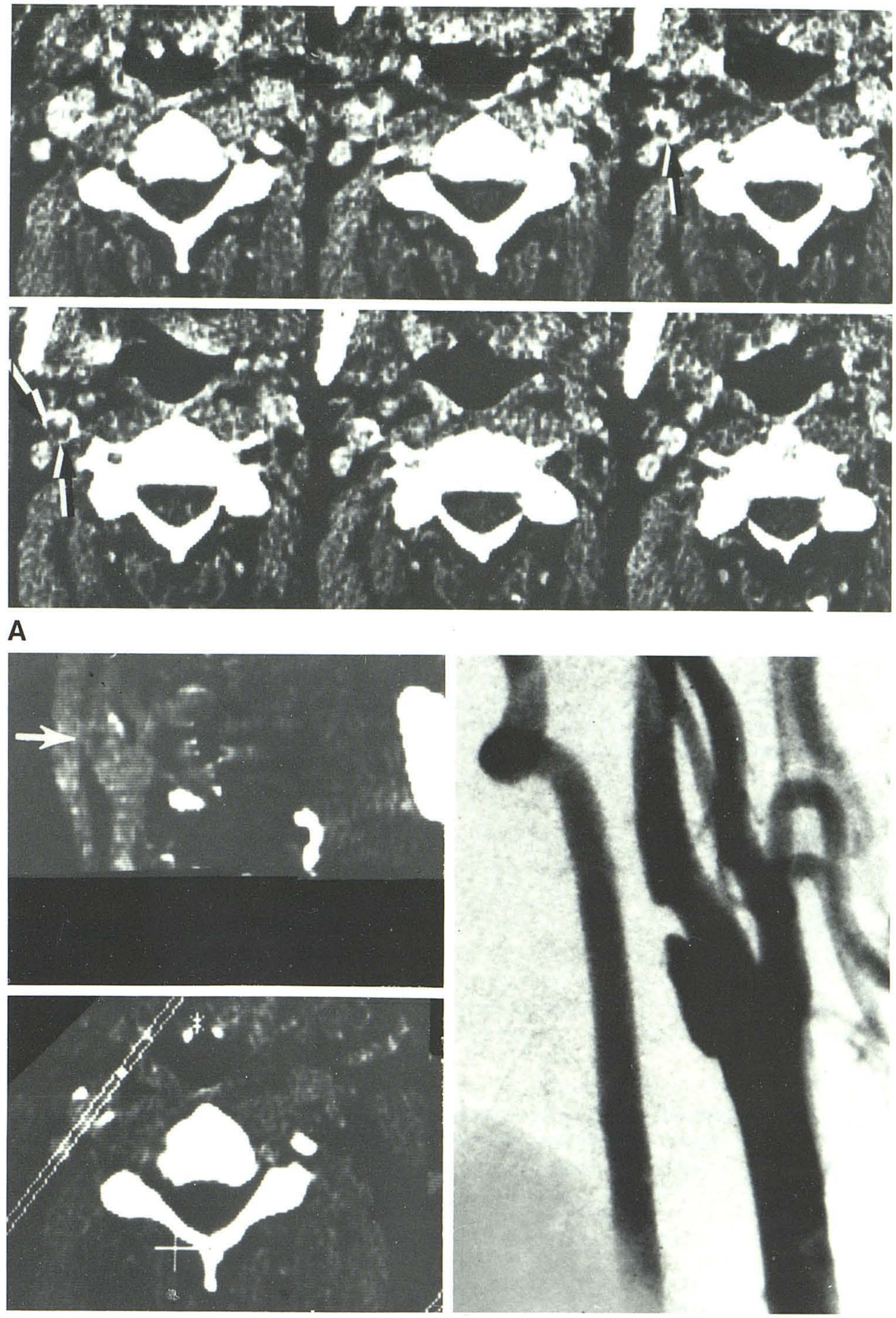
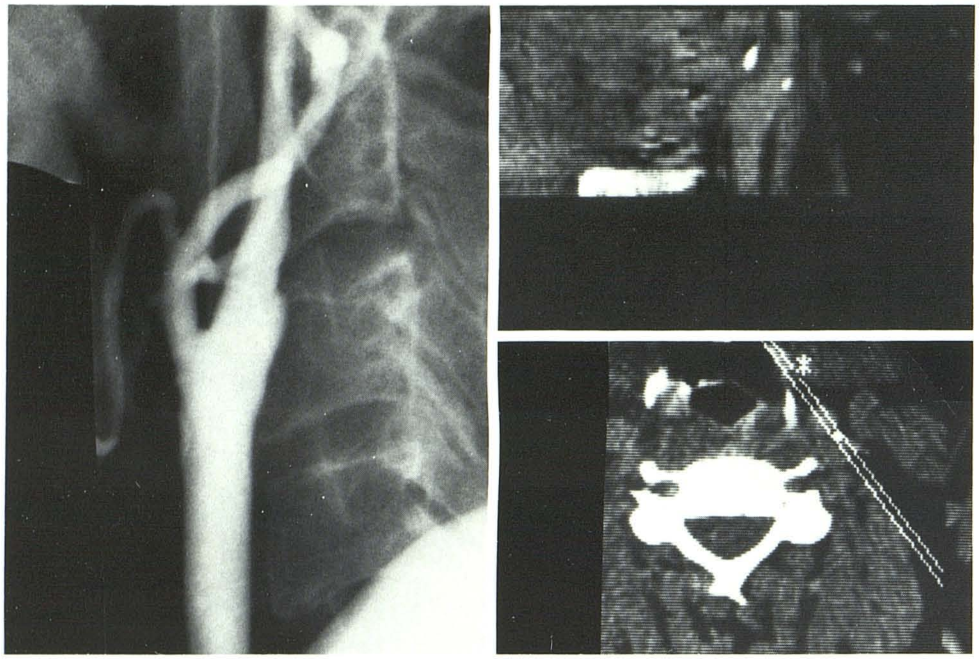


Fig. 5.—52-year-old man with recurrent transient ischemic attacks in right hemisphere. **A**, Selected axial CT sections starting at level of right carotid bifurcation. Filling defect due to thrombus (*arrows*) in calcified, ectatic internal carotid artery. **B**, Right anterior oblique reformation. Opacified bifurcation with intraluminal lucency (*arrow*), corresponding to thrombus on axial sections. **C**, Common carotid arteriogram defined large ulcer to better advantage but no direct evidence of thrombus.

vessel tortuosity; our equipment limits the long dimension of the study to 6.7 cm. Thus, a relatively limited segment of the carotid artery can be assessed in a single test. If a tortuous vessel exists the plane of the reformation, an occlusive lesion may be mimicked. For this reason, several planes may need to be reformatted, and cross-reference with the axial views at the level in question is necessary. Nevertheless, the method we describe has sufficient merit already to suggest its use in evaluating carotid patency in patients with trauma or neck masses and to suggest further investigation of its applicability in atheromatous disease.

In summary, high-resolution CT scanning of the carotid bifurcation is a potentially useful noninvasive screening procedure. Its major advantages include: (*1*) the use of currently available CT units without the need of purchasing new equipment; (*2*) little additional scan time or patient discomfort, with no added morbidity; (*3*) the ability to display the carotid bifurcation in multiple planes with image reformation



A B

Fig. 6.—Some patient as in figure 5. **A**, Shallow ulceration in left internal carotid on arteriogram. **B**, Reformation of left internal carotid. Focal calcification shown but not ulceration at site of lesion.

after the single injection of contrast material used for an enhanced brain CT study; and (*4*) more sensitive detection of thrombus or calcification due to the inherently superior density discrimination of CT. Although the initial limited experience with CT of the carotid bifurcation is promising, proof of the value of this technique must await detailed comparison studies with angiography and other screening methods.

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