Incremental Dynamic Computed Tomography: Practical Method of Imaging the Carotid Bifurcation

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Incremental Dynamic Computed Tomography:

Practical Method of Imaging the Carotid Bifurcation

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A simple, practical method of applying incremental dynamic computed tomography (CT) to the imaging of 20 carotid bifurcations is described. The results are compared with those obtained by conventional carotid angiography and intravenous digital subtraction angiography (DSA). Conventional angiography provided additional information about the carotid bifurcation in only one of 14 cases, while incremental dynamic CT provided information not available from intravenous DSA in two of eight cases. Conventional brain CT is being used increasingly in the workup of patients with transient ischemic symptoms, and dynamic CT scanning at 3-mm increments requires only an extra 5 min of scanner time. The addition of incremental dynamic CT through the carotid bifurcation to the conventional brain CT scan procedure may obviate other screening tests before more definitive angiographic procedures.

Embolism from atheromatous disease at the carotid bifurcation in the neck is the most common cause of transient cerebral ischemic attacks (TIAs) [1]. Despite the development of alternative, less invasive techniques, selective carotid angiography remains the definitive technique for demonstrating the anatomy of the carotid bifurcation. However, even in the best hands, carotid angiography has a significant morbidity and mortality [2], particularly when performed in elderly patients with symptomatic cerebrovascular disease and when there are marked stenoses of the internal carotid arteries [3].

Noninvasive techniques for the evaluation of the carotid bifurcation have been described and reviewed [4]. When used in the experienced, noninvasive vascular laboratory as a "battery" of tests, these methods can provide information about the severity and potential hemodynamic consequences of bifurcation disease with a maximum accuracy of about 90% [5]. The main purpose of the noninvasive battery, which monitors physiology as well as morphology, is to better select patients for arteriography.

Intravenous digital subtraction angiography (DSA) is a less invasive rapid procedure that can produce a 97% accuracy in the assessment of disease of the carotid bifurcation with good or excellent demonstration. However, inadequate studies occur in up to 15% of cases, and in these the accuracy is reduced to 64% [6].

Computed tomography (CT) is used increasingly in the evaluation of patients with TIAs to rule out hemorrhage, tumor, arteriovenous malformation, and demyelination, any of which may have clinical features simulating transient ischemia. The ability of CT to detect infarction and to distinguish lacunar from cortical infarction [7] may influence decisions concerning immediate management and further investigation. Methods of imaging the carotid bifurcation by CT have been described [8–11], but these are time-consuming or involve the use of sophisticated computer-based contour programs not readily available. The object of our study was to develop a rapid, practicable method of imaging the carotid bifurcation that could be used as an adjunct to the standard cerebral CT examination in the evaluation of patients with TIAs.

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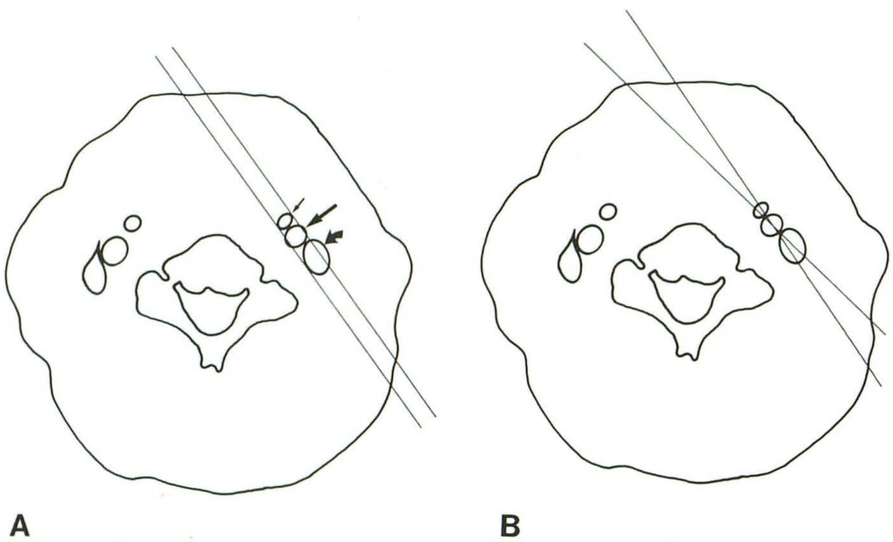

Fig. 1.—Diagrams of axial CT image of neck immediately superior to carotid bifurcation. **A**, Internal jugular vein (*curved arrow*), internal carotid artery (*long straight arrow*), and external carotid artery (*short straight arrow*). *Parallel lines* indicate limits of contiguous paraxial reformations. **B**, Variations in paraxial planes along which reformations are made.

Fig. 2.—Normal carotid bifurcation. Paraxial reformatted images are 1 (**A**), 2 (**B**), and 3 (**C**) pixels thick.

Subjects and Methods

Ten patients presenting with internal carotid territory TIAs had a thorough history and examination performed by a neurologist (S. D.). Seven patients were investigated with bilateral transfemoral carotid angiography and four with intravenous DSA. One patient had both carotid angiography and intravenous DSA. All patients had a CT examination on a GE 9800 scanner within 4 days of angiography. The CT examination consisted of an incremental dynamic CT evaluation of the carotid bifurcation in the neck and a subsequent cerebral scan.

An 18- or 20-gauge intravenous sheath (Jelco IV Catheter Placement Unit, Critikon, Tampa, FL) was introduced into an antecubital vein and connected by plastic tubing to a mechanical pump (Cordis flow rate injector). Fifty to eighty ml of Urografin 76% (10% meglumine diatrizoate and 66% sodium diatrizoate, Schering) was injected at rates of 2–8 ml/sec. A lateral computed radiograph (ScoutView, GE, Milwaukee) of the cervical spine was obtained. Between 12 and 16 contiguous axial scans of 3 mm slice width were obtained from the level of the middle of the fifth cervical vertebra to the upper margin of the third cervical vertebra. The incremental dynamic program was used with increments of 3 mm, 2 sec scan durations, and interscan intervals of 2.3 sec. Preparation delays (the interval from the beginning of contrast-medium injection to commencement of scanning) of 8–14 sec were incorporated. At the completion of the dynamic scan program, a standard, postenhancement head scan series was obtained.

Inspection of the hard-copy axial neck images enabled the sites of the common carotid bifurcation and internal and external carotid arteries to be determined. An image clearly depicting the proximal segments of the internal and external carotid arteries was selected. Using the standard "Arrange" program (GE, Milwaukee), paraxial images were reformatted along the axis of the internal and external carotid arteries at 1, 2, or 3 pixel (0.5 mm, 1 mm, or 1.5 mm) intervals (fig. 1A). The "batch mode" software program (GE, Milwaukee) enabled these multiple reformations to be subsequently computed. Slight variations in the paraxial plane chosen for reformation (fig. 1B) were reviewed so that the plane best depicting the maximum diameter of the internal carotid artery was selected for hard-copy recording. The procedure was repeated for the opposite carotid bifurcation. The images were displayed with window levels of 100–150 H and window widths of 100–250 H. The image was photographed either as a standard negative image or as a positive image by using the "video reverse" command.

The degree of stenosis of the origin of the internal carotid artery as seen on carotid angiography, intravenous DSA, and incremental dynamic CT was graded on a 0–6 scale: 0 = normal, 1 = minimal stenosis (1%–19%), 2 = mild stenosis (20%–39%), 3 = moderate stenosis (40%–49%), 4 = moderate to marked stenosis (60%–79%), 5 = marked stenosis (80%–99%), and 6 = complete occlusion, according to the method described by Chilcote et al. [6]. In comparing

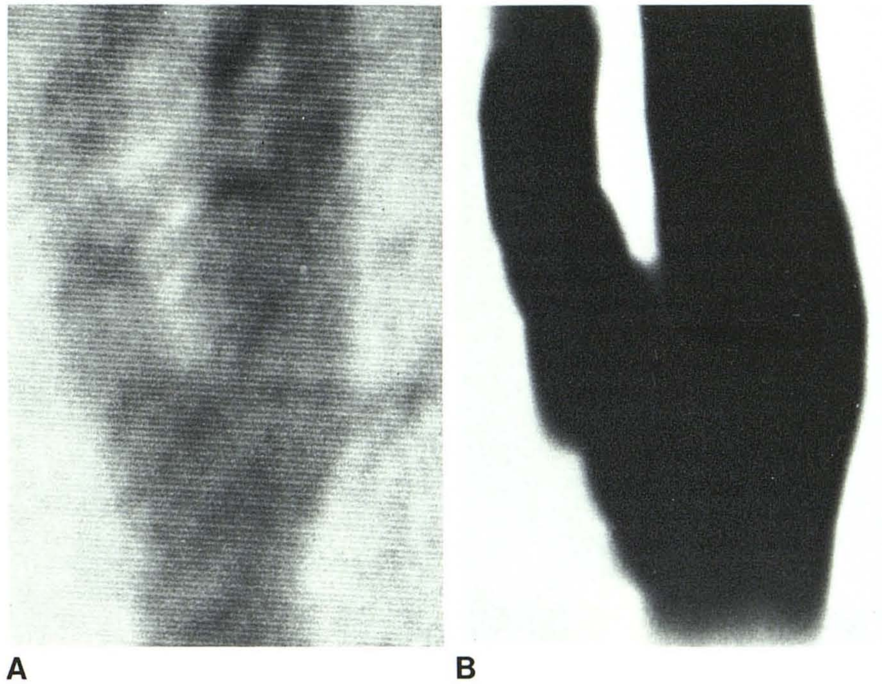

Fig. 3.—Normal common carotid bifurcation. Intravenous DSA (**A**) and incremental dynamic CT (**B**). Internal carotid artery is on reader's right.

the results of incremental dynamic CT with intravenous DSA or carotid angiography, the findings were regarded as concordant if there was no more than one grade difference in the perceived degree of stenosis.

The images obtained by incremental dynamic CT (including axial and reformatted images), DSA, and carotid angiography were graded as poor, acceptable, or excellent. An *excellent* study was one in which the lumen of the terminal part of the common carotid artery and proximal 2 cm of internal carotid artery were clearly seen on axial and reformatted images, without movement-induced artifacts. An *acceptable* image was one on which diagnostic information was considered to be available, although the image was not of optimal quality. A *poor* image did not allow sufficient information for diagnosis. The quality of reformations using 1 pixel width (0.5 mm), 2 pixels (1 mm), and 3 pixels (1.5 mm) was compared, as was that of reformations using "soft-tissue," "standard," and "bone" computer reconstruction algorithms.

Results

The quality of all of the studies was classified as acceptable or excellent. Both standard and soft-tissue computer reconstruction algorithms resulted in reconstruction quality vastly superior to those obtained using the bone algorithms. The quality of the reformatted images obtained by reformations using thicknesses of 1, 2, and 3 pixels was not significantly different (fig. 2).

Of the 20 bifurcations imaged by incremental dynamic CT, five were considered to be normal, 11 showed degrees of stenosis (seven minimal to mild, grades 1 and 2; two moderate to marked, grades 3 and 4; and two marked, grade 5) and four were completely occluded. Examples of each of these categories are illustrated (figs. 3–5). In only one of 14 bifurcations imaged by incremental dynamic CT and carotid angiography were the results of the evaluations discordant. In that case both carotid angiography and incremental dynamic CT showed bilateral internal carotid occlusions, but carotid angiography also showed that the left external carotid artery was occluded. In addition, carotid angiography demonstrated that two patients had moderate to marked middle cerebral artery stenosis.

Eight carotid bifurcations were imaged by both incremental dynamic CT and intravenous DSA. In six of the eight the results were concordant. In one case intravenous DSA failed adequately to demonstrate one of the carotid bifurcations, because of laryngeal artifact and overlap of vessels. In a second case, intravenous DSA was reported to show left internal carotid occlusion (grade 6). Incremental dynamic CT revealed a thin stream of contrast medium in the patent, but severely stenosed, internal carotid artery (grade 5), a finding confirmed by carotid angiography (fig. 6).

A preparation delay of at least 14 sec between injection of contrast medium and scanning was necessary to ensure that the common and internal carotid arteries were satisfactorily opacified on the first scan, as 8 sec delays in some patients with myocardial disease and limited cardiac output did not allow the contrast medium to reach the carotid arteries in time for the first scan. A contrast-medium injection rate as slow as 2 ml/sec adequately opacified all of the neck vessels. Postenhancement scans showed no abnormality in four patients, white-matter ischemia and lacunae in four, a recent cortical infarct in one, and a chronic subdural hematoma in one.

Discussion

Carotid angiography remains the definitive technique for the evaluation of the carotid circulation, including the carotid

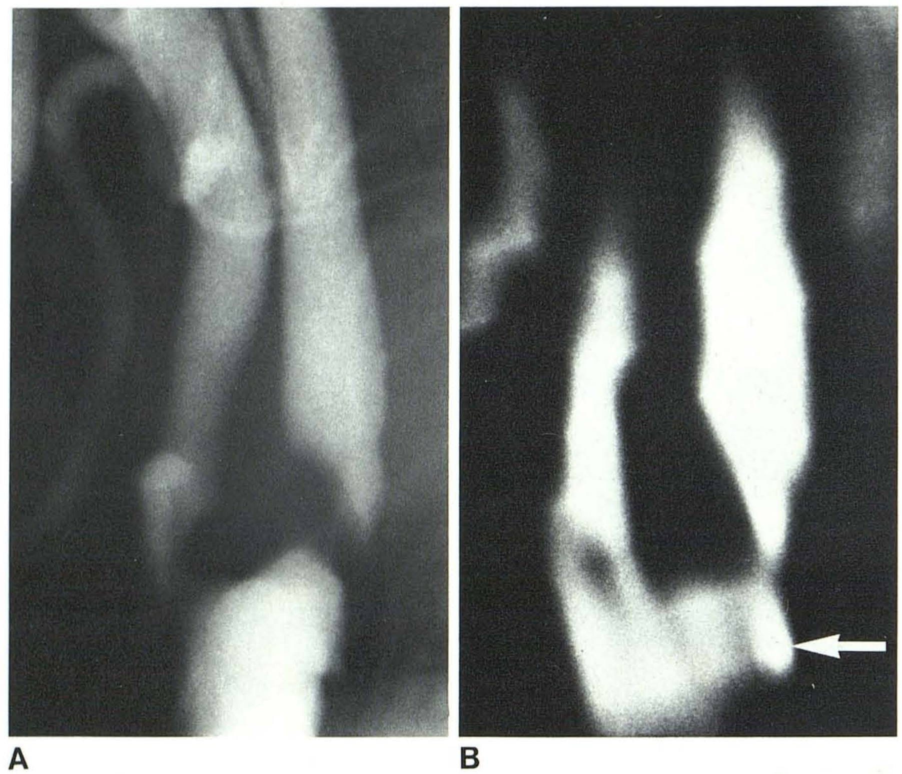

Fig. 4.—Carotid angiogram (**A**) and incremental dynamic CT scan (**B**). Marked stenosis (grade 5) of internal and external carotid arteries. Calcified plaque at origin of internal carotid artery (*arrow*).

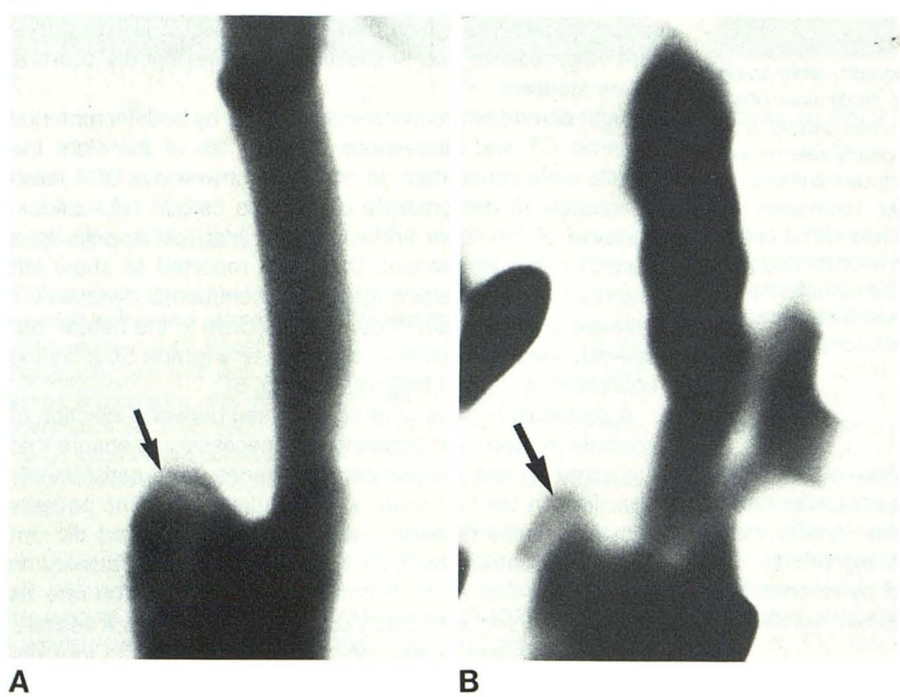

Fig. 5.—Carotid angiogram (**A**) and incremental dynamic CT scan (**B**). Occluded internal carotid artery (*arrows*).

bifurcation. In all 14 carotid bifurcations imaged by both incremental dynamic CT and carotid angiography, the CT-generated images of the bifurcation were considered to be concordant with the angiographic data in estimating the degree of stenosis of the internal carotid artery, although carotid angiography showed occlusion of an external carotid artery not detected by CT in a patient who had bilaterally occluded internal carotid arteries. Management would not have been

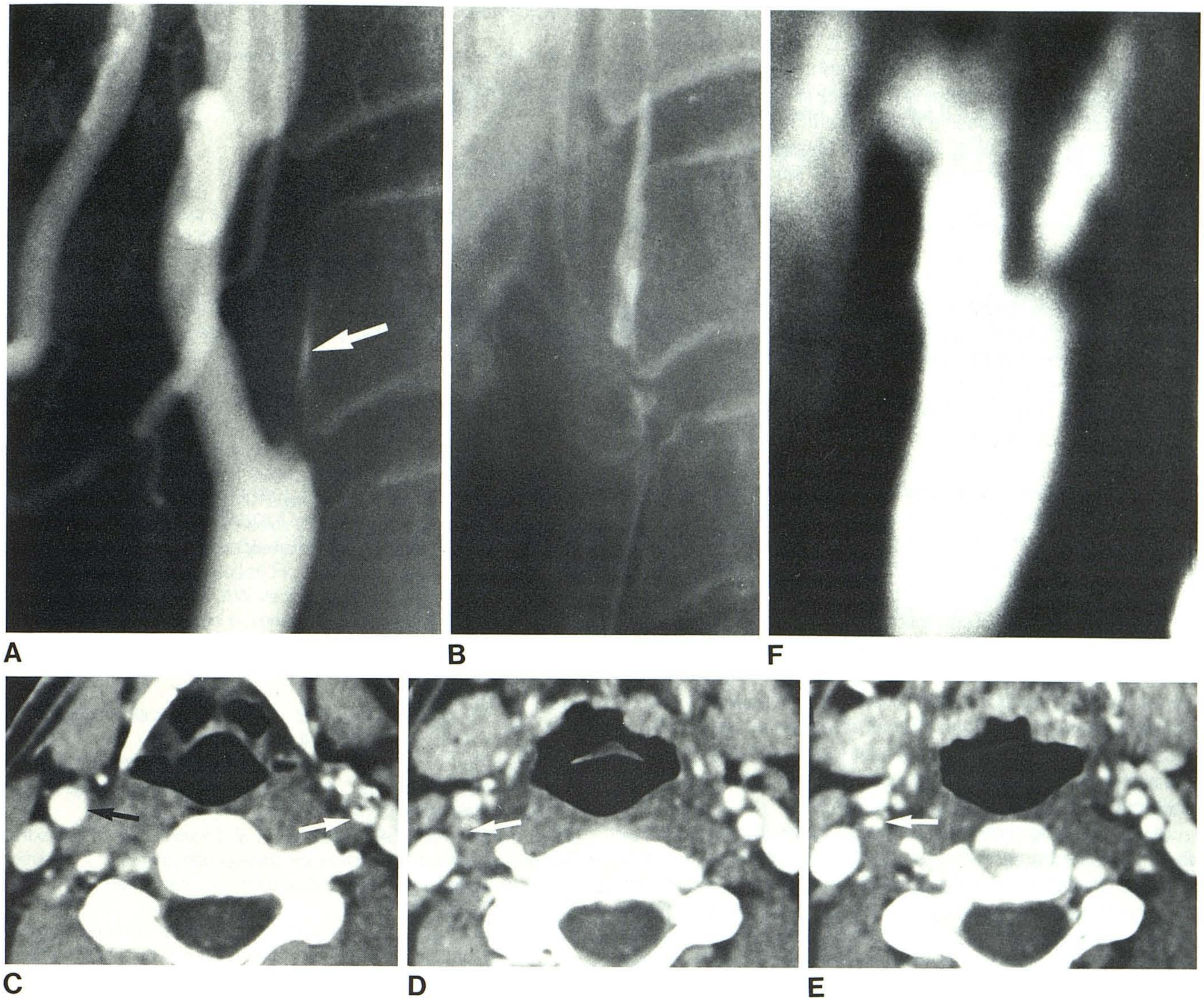

Fig. 6.—**A**, Carotid angiogram, arterial phase. Sliver of contrast medium (*arrow*) in severely stenosed right internal carotid artery. **B**, Carotid angiogram, venous phase. Very slow passage of contrast medium through internal carotid artery. **C**, Axial CT scan through neck 3 mm inferior to termination of right common carotid artery. Right common carotid artery is normal (*black arrow*). Left internal carotid artery is moderately stenosed at its origin (*white arrow*). **D**, Axial CT scan through origin of right internal carotid artery. Right internal carotid artery is almost occluded by atheromatous plaque containing fat-density material. Only a tiny contrast-medium-containing lumen remains (*arrow*). Left internal carotid artery is of normal caliber at this level. **E**, Axial CT scan 3 mm above **D**. Right internal carotid artery now has larger contrast-medium-containing lumen (*arrow*) than in **D**. Rest of true lumen contains relatively isodense thrombus. **F**, Paraxial reformation through right internal carotid artery origin. Severe stenosis and thin distal column of contrast medium.

affected in this patient, as formal angiography was essential as a prelude to extracranial-intracranial bypass surgery.

Incremental dynamic CT and intravenous DSA were discordant in the assessment of two of eight carotid bifurcations. A swallowing-induced misregistration artifact on one projection and an overlap of vessels on the other prevented the demonstration of one carotid bifurcation in the first case. This is a well recognized problem with intravenous DSA [12]. One of the distinct advantages incremental dynamic CT has over intravenous DSA is that each vessel can be clearly distinguished on axial CT images and paraxial reformatted images. The sensitivity of incremental dynamic CT in detecting high degrees of stenosis was graphically demonstrated in a second patient, whose intravenous DSA study had indicated occlusion of an internal carotid artery (fig. 6). The carotid angiogram showed only a very thin column of contrast medium within the proximal segment of the internal carotid artery, due to slow flow of contrast material and consequent layering. However, efficient dispersion of contrast medium throughout the intravascular compartment and the sensitivity of CT to even very dilute iodine concentrations allowed incremental dynamic CT to demonstrate clearly the full extent of the residual lumen of the severely stenosed internal carotid artery (fig. 6). Differentiation between severe stenosis and occlusion is extremely important, as the demonstration of patency allows the possibility of endarterectomy and thrombectomy with successful restoration of a normal internal carotid artery lumen [13].

Two of the patients investigated by CT and carotid angiography were shown by carotid angiography to have significant middle cerebral artery stenoses. Such lesions cannot be detected by the noninvasive carotid tests and are unreliably diagnosed by intravenous DSA [14]. Earnest et al. [14] reported an 8% incidence of "significant" intracranial atheromatous lesions in their comparison of intravenous DSA and conventional angiography in 78 patients and found that these intracranial lesions were often missed by intravenous DSA.

A 3 mm slice width is very practical, allowing the scanning of 4–5 cm of the common carotid artery and its internal and external carotid branches. Slices of 1.5 mm are impractical, because tube heat-loading limits prevent more than a 1.5–2 cm segment being scanned using the incremental dynamic scan program. Five mm slices result in a loss of spatial resolution and unacceptable image degradation on reformatted images.

Incremental dynamic CT is a simple technique and only adds about 5 min to the time taken for a normal contrast-enhanced CT scan. This incorporates the time involved in connecting and securing the intravenous catheter to the mechanical pump and about 1.5 min of scanning time. A conventional head scan can follow immediately. Reformations can be done electively, using the standard Arrange program (GE, Milwaukee), in about 15 min. Operator time can further be reduced by using the "batch mode" option, which allows the reformations to be done after all other computer functions. Patient tolerance is excellent. Instructions other than to keep still are unnecessary with scan durations of 2 sec per scan. Swallowing does not constitute a problem.

At present, the technique is limited to evaluating only the terminal common carotid artery and proximal 2–3 cm of the internal carotid artery. However, most clinically significant atheromatous disease occurs in this segment of the carotid arterial tree [1]. Although incremental dynamic CT cannot reliably detect ulceration, both intravenous DSA and carotid angiography may identify only 50% of surgically confirmed ulcers [14].

Contrast-medium volumes of 140–175 ml are generally used for intravenous DSA studies of the carotid system [15]. In a series of 2488 patients studied with intravenous DSA, four (0.16%) suffered complications related to the total volume of contrast medium [16]. Reducing the volume of contrast medium to a maximum of 80 ml has been recommended for patients with a cardiac history, diabetes, or renal impairment [16]. Incremental CT does not require more than 80 ml of contrast medium.

Cerebral CT scans are increasingly regarded as part of the protocol in the evaluation of patients with TIAs. This preliminary study suggests that the addition of incremental dynamic CT of the carotid bifurcation to the cerebral CT scan can provide valuable and accurate anatomic information, which can help select those patients requiring a more definitive angiographic procedure.

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