Computed Tomographic Evaluation of Cervical Carotid Plaque Complications

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SUMMARY Twenty five patients with manifestations of cerebrovascular ischemic disease were evaluated with high resolution computed tomography of the neck, following intravenous infusion of a contrast agent. Computed tomography images of extracranial carotid arteries revealed atherosclerotic plaque formations and their complications: stenosis, occlusion, ulceration, calcification and mural lucent defects. Histologic analysis of 15 endarterectomy specimens obtained from symptomatic patients who had computed tomography images of discrete lucent defects in carotid plaques demonstrated subintimal hemorrhage of varying age in 13, focal necrosis in 1 and excessive subintimal thickening in 1. It is concluded that lucent images observed in computed tomography of extracranial carotid arteries represent vascular wall lesions within carotid plaques suggestive of subintimal hemorrhage, focal necrosis and/or excessive subintimal thickening. Computed tomography of the extracranial carotid arteries is a relatively non-invasive method that permits the diagnosis of plaque hemorrhages in symptomatic and asymptomatic carotid arteries.

Atherosclerosis of the cerebrovascular system is a focal disease of the arterial wall characterized by the development of a plaque consisting of abnormal proliferating tissue that disrupts the intima. Clinical manifestations appear when the plaque becomes complicated by the development of hemorrhage, calcification, ulceration, thrombosis or occlusion.1

Conventional angiography identifies carotid plaque complications such as stenosis and occlusion of the arterial lumen as well as ulceration of the luminal surface, but fails to demonstrate other mural changes that may intervene in the development of clinical manifestations, such as plaque hemorrhage and necrosis of the arterial wall.

Recent studies2-3 have shown a high incidence of intramural hemorrhages in specimens of carotid arteries of patients subjected to endarterectomy with appropriate cerebral ischemic manifestations. Carotid plaque hemorrhages are occasionally suspected when a mounding protrusion appears in the conventional arteriogram.2 They are diagnosed when observed in carotid specimens obtained from endarterectomies, although questions concerning the development of hemorrhages during surgical manipulation have been raised.2 Considering the clinical relevance of intraplaque hemorrhages and the lack of a reliable method to identify them before surgical intervention, we explored the possibility of detecting intramural hemorrhages and other complications in carotid artery plaques using computed tomography (CT) techniques.

Methods

We obtained CT scans of the neck in 25 patients with manifestations suggestive of carotid disease, who had been clinically investigated in the conventional way with angiography and CT of the head. A G.E. 8800 scanner was used to obtain high resolution CT scans of the cervical region using a technique presented elsewhere4,5 and summarized herein. A lateral digital scout image was obtained to direct the level of slices (fig. 1). Dynamic scans were made from the bottom of the C2 vertebral body to the mid-portions of the C6 vertebral body, unless otherwise indicated by previous conventional or digital subtraction angiography. Meglumine iohexalate 60% (Conray 60) was injected in an antecubital vein using an initial 100 cc. bolus spread over the period of the dynamic sequence (average 3 minutes). This was followed by a drip infusion of an identical volume and concentration of the contrast agent. Shortly after initiating the bolus injection, dynamic overlapping 5 mm thick CT slices were obtained in the axial plane at 2.5–3.5 mm automatic table increments, up to a maximum of 16 slices. During the dynamic sequence, scan time was 9.6 seconds at 160 milliamperes/second, and interscan time was between 1 and 2 seconds. At the completion of the dynamic study, an additional set of 24–43 contiguous, 1.5 mm high resolution slices were obtained through the same region using a soft tissue algorithm. With increasing experience we have learned that the second sequence with drip infusion does not add substantial information and has been abandoned in favor of the dynamic sequence following the bolus injection. The average calculated radiation dose for the high resolution images was 6.3 rads skin dose, as estimated by thermoluminescent dosimetry. Axial images were recorded and later used to direct image reformation in the sagittal, parasagittal and oblique planes, a technique considered to be optional since it adds little to the evaluation of carotid artery disease.

Patients were managed according to clinical manifestations and conventional angiographic criteria. Carotid endarterectomy was performed in 19 patients. Specimens obtained at the time of operation were analyzed histologically with light microscopy in serial sections stained with hematoxylin and eosin.
Results

The subjects (17 male, 8 female) had an age range of 39–77 years (average 58.5 years). Nine patients had transient ischemic attacks, 7 patients had reversible ischemic neurologic deficits, 8 patients had stroke and 1 patient had unlocalized symptoms. Twelve right carotid arteries were symptomatic, 12 left carotid arteries were symptomatic and 26 carotid arteries were asymptomatic (the patient with unlocalized symptoms was included in the carotid asymptomatic group). The interval between the latest symptom and the performance of the CT was less than 4 weeks in 18 patients, between 4 and 8 weeks in 2 patients, between 8 and 12 weeks in 1 patient, more than 1 year in 1 patient and unknown in 2 patients.

Carotid vessels were located in CT images of the neck immediately lateral and slightly anterior to the vertebral body, lateral and slightly posterior to the pharyngeal cavity and medial to the sternocleidomastoid muscle (SCM) (fig. 2). Distal to the bifurcation both external and internal carotid arteries were easily identifiable. Usually the internal carotid artery was found lateral and posterior to the external carotid, although their anatomical relationship varied from one individual to another. In general, the internal jugular vein appeared as a large contrast-filled vessel posterolateral to the carotid bundle and medial to the SCM (fig. 2). In normal individuals the CT images of the vascular wall merged with the image of the contrast filled lumen and could not be individualized.

Carotid plaques were identified in serial CT images of the neck by the irregularly calcified, frequently constricted contour of the vascular wall, encircling a contrast-filled lumen. Images of irregular vascular wall contours were more prominent at the carotid bifurcation or in its immediate vicinity. Mural calcification was indicated by high density defects irregularly embracing the arterial lumen, or incrusted in the vascular wall. Ulcerations were characterized by minute outpouchings of the circulating contrast material into the thickened or lucent arterial wall.

In 18 symptomatic carotid arteries and in 10 asymptomatic carotid arteries we observed discrete radiologic lucent defects in the vascular wall. Their size and shape varied from a small ball image to a comma or slit-like defect embedded circumferentially in a segment of the vascular wall. Lucent defects were commonly associated with calcium deposits and luminal compromise (see illustrative cases).

To investigate the nature of lucent defects we studied histologically carotid artery specimens obtained from 15 endarterectomies in the group of 18 symptomatic patients whose CT study of neck vessels had shown lucent defects. In 13 specimens (fig. 3) we found subintimal accumulation of old hemorrhagic material in the midst of thickened, lipid-laden plaques; not infrequently pockets of fresh blood were also observed. In one specimen there was focal mural necrosis and in another there was prominent intimal thickening without evidence of hemorrhage. These findings suggest that lucent defects observed by CT scan in carotid walls are the radiological image of subintimal old and fresh hemorrhagic lesions, focal necrosis, excessive subintimal thickening or a combination of these histologic abnormalities. In the remaining 6 symptomatic patients, whose CT had not revealed lucent defects, 4...
Morphologic Characteristics of Plaques and CT Findings

24 symptomatic carotids
18 carotids with lucent lesions
15 histologic analysis
13 intramural hemorrhage
1 focal necrosis
1 subintimal thickening

Figure 3. Morphologic characteristics of plaques and CT findings in 24 symptomatic carotid arteries.

patients were intervened by endarterectomy and the histological analysis showed a small intraplaque hemorrhage in one specimen.

The distribution of plaque complications according to the CT study of 50 carotid arteries in our series is shown in fig. 4.

Illustrative Cases

Case 1

Fifty-three year old man with episodes of transient cerebral ischemia manifested by numbness of the right hand and independently intermittent visual disturbance of the left eye occurring one month before evaluation. Physical examination revealed bilateral carotid bruits. Conventional angiography showed bilateral proximal internal carotid tight stenosis (fig. 5). CT of the neck with vascular contrast enhancement (fig. 6) showed extensive calcific atheromatous plaque formation of the left common carotid bifurcation and of the proximal 1 cm segment of the internal carotid artery, a periluminal lucent defect elongated posteriorly and severe luminal narrowing of the involved internal carotid segment. On the right side there was extensive calcific atheromatous plaque formation of the carotid bifurcation and proximal internal carotid. A left internal carotid endarterectomy demonstrated a 2 cm long plaque involving 1 cm of the distal common carotid and 1 cm of the proximal internal carotid. Histological examination showed calcific deposits, a large organized mural thrombus with a pocket of fresh hemorrhage, cholesterol inclusions, foci of inflammation and angioneogenesis (fig. 7).

Figure 5. (Case #1). Left carotid conventional arteriogram shows severe stenosis of the proximal 1 cm segment of the internal carotid artery.
Figure 6. (Case #1). CT of the cervical region at the level of the proximal internal carotid artery with vascular contrast enhancement. On the left high density lesions are observed on the medial and lateral carotid wall (CA) indicative of calcium deposits, and an elongated posterior lucent defect (L) surrounding a highly stenotic, contrast-enhanced, slit-like lumen (LM). On the right there is dense calcification of the carotid wall (CA) and a stenotic lumen (LM).

Case 2

Fifty-nine year old man suffered episodes of right amaurosis with residual right upper nasal quadrant defect 8 days before evaluation. Funduscopic examination revealed a Hollenhorst plaque on the right. Carotid bruits were not heard. Conventional angiography showed on the right a bilobulated defect at the bifurcation suggestive of intimal ulceration (fig. 8) and on the left an irregular defect at the level of the carotid bifurcation consistent with atheromatous plaque formation. CT of the neck with vascular contrast enhancement (fig. 9) showed on the right, mural calcification at the carotid bifurcation, circumferential periluminal luency and a posterior niche invaded by luminal contrast material suggestive of ulceration. On the left side there was extensive calcification and occasional minor lucent defects at the bifurcation. Histological analysis of the right carotid endarterectomy specimen demonstrated mural calcification, thickening of the vascular wall and ulceration of the intima with pockets of fresh blood lining the lateral walls of the crater (fig. 10).

Case 3

Sixty-nine year old man with transient episodes of speech disturbance and right upper extremity numbness occurring 3 weeks before the radiologic studies. On examination there was minor dysphasia and left carotid bruit. Conventional angiogram showed high grade stenosis of proximal left internal carotid artery (fig. 11) and occlusion of right internal carotid. CT of the neck with intravenous contrast enhancement (fig. 12) showed on the left side calcium deposits on the anteromedial aspect of the proximal internal carotid artery, circumferential mural lucencies and a large lucent defect posteriorly with narrowing of the lumen. On the right side absence of luminal contrast enhancement distal to the carotid bifurcation suggestive of occlusion, and mural calcifications. Histological analysis of the left internal carotid specimen following endarterectomy demonstrated focal calcifications, a large organized thrombus, mural necrosis and subintimal thickening (fig. 13).

Discussion

CT of the cervical region permits the radiological visualization of neck vessels with enough detail to
FIGURE 9. (Case #2). CT scan of the cervical region with vascular enhancement at the level of the bifurcation shows mural calcification (CA), a circumferential periluminal lucency (L) in the shape of two hemispheres and a posterior niche (U) suggestive of ulceration; the contrast-enhanced lumen (LM) has the form of a horizontal bar separating both lucent hemispheres. On the left there is extensive vascular calcification (CA) and minor lucent defects.

allow the recognition of mural irregularities suggestive of carotid atheromatous plaque formation. Furthermore, it permits the identification of plaque complications such as hemorrhage, calcification, ulceration, stenosis and occlusion that determine the appearance of clinical manifestations.

In our study of 50 carotid arteries comparison of CT and angiographic findings showed that mural calcification was best identified with CT, whereas luminal stenosis, ulceration and occlusion were detected by either method (fig. 14). Conventional angiography failed to visualize radiologically intramural soft tissue lesions such as hemorrhage or focal necrosis. Intramural lucenties complicating carotid plaques were commonly observed in CT images. The light microscopy study of 15 specimens revealed that mural lesions such as old and fresh hemorrhage, focal necrosis and subintimal thickening were found where the CT had shown discrete lucent defects suggesting that intramural hemorrhage, focal necrosis and/or excessive subintimal thickening determine individually or in combination the radiologic image of a lucent defect.

Hemorrhage is a common carotid plaque complication. We found hemorrhages in 14 of 19 endarterectomy specimens studied histologically. Their appearance ranged from collections of intact red blood cells to hemorrhagic debris, amorphous material and organized thrombus indicative of various ages. In their prospective study of 376 carotid artery plaques Imparato et al found that intramural hemorrhage was the most

FIGURE 10. (Case #2). (Hematoxylin, eosin. Magnification x 12.5). Section of right carotid endarterectomy specimen showing calcification (CA), mural thickening and ulceration of the intima (U) with pockets of fresh blood (H) lining the lateral wall of the crater.

FIGURE 11. (Case #3). Left carotid arteriogram shows high grade stenosis of proximal internal carotid artery and of external carotid artery.
Comparison of CT vs Angiographic Findings in 50 Carotid Arteries at Bifurcation

FIGURE 12. (Case #3). CT of the cervical region with vascular contrast enhancement shows on the left calcium deposits (CA) and a circumferential mural lucency more prominent posteriorly (L). The lumen (LM) is irregularly stenotic. On the right side there is circumferential calcification (CA) and absence of contrast-enhanced lumen suggestive of occlusion.

common plaque complication associated with appropriate symptoms \( p < 0.02 \) when compared with asymptomatic plaques. In another prospective study Lusby et al\(^2\) observed a recent intraplaque hemorrhage in 92.5% of symptomatic patients undergoing endarterectomy compared to 27% in asymptomatic patients. Plaque hemorrhages have been associated with plaque growth and increased degree of plaque-induced stenosis of the arterial lumen \(^3\)\(^\text{-}^5\). They have been implicated directly in the precipitation of ischemic cerebral events through the reduction in flow when the plaque protrudes into the lumen, and/or through the breakdown of the luminal surface with release of embolic material.\(^6\)

The identification of discrete lucent defects by CT, particularly if large and of irregular shape in symptomatic carotid arteries suggests the presence of a plaque complication, most likely a hemorrhage, responsible for the symptoms. However, from the study of CT images in this series we were unable to determine the age of the lesion, and where hemorrhages were found in the endarterectomy specimen we could not discriminate by the CT scan image whether the collection was recent or old, i.e. fresh blood, amorphous material or organized thrombus. CT findings such as these may strengthen the resolve to intervene surgically or may incline the argument in favor of an endarterectomy, if future studies show a heightened risk for development of stroke in patients with CT images of carotid plaques with lucent complications.

The observation of lucent defects in asymptomatic arteries may also have value. In our series we observed intramural lucencies in 10 asymptomatic carotid arteries (fig. 4); their histologic correlation remains unknown since patients without clinical manifestations are not operated in our center. However, intramural hemorrhages may occur in asymptomatic carotid arteries, as shown by Lusby et al\(^2\) who found this complication in 27% of asymptomatic patients. It is likely that lucent lesions observed in asymptomatic carotid arteries in our patients represent mural hemorrhages, focal necrosis or excessive thickening. In this regard CT of the neck could assume a most important role in determining the conduct to follow in asymptomatic carotid plaques that have reached the stage of pathologic complications.

To conclude, CT of the cervical region is a relatively non-invasive method that permits the investigation in vivo of carotid plaque complications that lead to clinical manifestations, among which mural hemorrhage assumes a most important role. Furthermore, it allows the serial study of asymptomatic carotid lesions and may indicate the presence of carotid plaque complications in the pre-symptomatic stage, providing an additional element of judgment in their management.

FIGURE 13. (Case #3). (Hematoxylin, eosin. Magnification \( \times 12.5 \)). Section of left carotid endarterectomy specimen shows focal necrosis (N) and organized thrombus (T). Residual calcium deposits (CA) are observed in the vascular wall.

FIGURE 14. Comparison of CT and angiographic findings in 50 carotid arteries at bifurcation.
Delayed Cerebral Ischemia Following Arteriography

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SUMMARY Cerebral ischaemic events associated with arteriography are usually attributed to catheter-induced emboli. We present three patients with cerebral ischemia occurring 6 to 48 hours post-arteriography. We suspected that alternate pathogenic mechanisms were in effect. To evaluate the possibility that sustained platelet activation occurs in association with arteriography, we measured the platelet-specific protein beta thromboglobulin (BTG) prior to and 24 hours following arteriography in two groups of patients. Group I had arteriography performed shortly after venipuncture, while Group II patients did not have arteriography between samples. Seven of eight Group I patients had an increase of BTG on day two, compared with two of eight group II patients (p < .05). When compared to Group II changes, Group I had a significant increase of BTG on day two (p < .05). We conclude that cerebral ischemic events associated with arteriography may occur on a delayed basis, and that platelet activation, manifested by increased BTG levels, may be one mechanism contributing to this phenomenon.

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References

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Case Reports

Case 1
A 65 year old female, admitted for evaluation of an abdominal aortic aneurysm, sustained a right hemisphere stroke nine years previously. At that time, she experienced an incompletely resolving sensori-motor deficit involving left arm and leg along with dysarthria. She had chronic hypertension and adult onset diabetes controlled with oral agents. General physical examination revealed a pulsatile abdominal mass. The cardiac exam was normal. Neurological examination showed a normal mental status. A cholesterol embolic fragment was noted on funduscopic exam of the right eye. There was mild weakness of the left iliopectoas, with left-sided hyperreflexia and a left Babinski. Admission laboratory evaluation was unremarkable.

The patient underwent an aortic arch study, which demonstrated an abdominal aortic aneurysm and occlusions of both superficial femoral arteries. There were non-occluded, non-flow-restricting plaques at both carotid bifurcations. Beginning 6 hours following the procedure, the patient experienced at least three episodes of transient right upper extremity sensori-motor deficit, each lasting minutes. These occurred...
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