Evaluating Cross-Sectional Luminal Morphology in Carotid Atherosclerotic Disease by Use of Spiral CT Angiography

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Background and Purpose—This study sought to determine the frequency of noncircular lumens in patients with significant carotid atherosclerotic disease and to evaluate the effect of noncircular lumens on stenosis measurement derived from angiographic projections.

Methods—One hundred consecutive patients presenting with an internal carotid artery stenosis of at least 50% were imaged with spiral CT angiography. The transverse morphology of the diseased lumen was assessed on axial images, and the frequency of noncircular lumens was determined. In these cases, maximum intensity projection angiograms were reconstructed in standardized angiographic planes and in a plane selected according to the luminal obliquity, which was chosen to optimize the angiographic representation of the maximal stenosis. North American Symptomatic Carotid Endarterectomy Trial (NASCET) measurements were calculated from the maximum intensity projection images, and differences between values obtained from standard and optimized projections were recorded.

Results—Noncircular lumens were observed in 18 of 100 patients and consisted of elliptical and linear transverse profiles. The transverse orientation of the lumen in these cases ranged from +90° to −87° relative to the anteroposterior plane. An increase in the calculated NASCET stenosis was demonstrated when measurements were obtained from angiographic reconstructions obtained in the exact plane of the luminal obliquity compared with standard angiographic projections. As a result, the stenosis severity was upgraded from moderate to severe in 2 patients.

Conclusions—Noncircular transverse luminal profiles are not uncommon and may introduce error into NASCET calculations obtained from standard angiographic projections. (Stroke. 2001;32:2511-2515.)

Key Words: carotid • CT angiography

Extracranial carotid atherosclerosis is well established as an important risk factor for the development of thromboembolic cerebrovascular disease. Several international multicenter trials have established the efficacy of endarterectomy in patients with high-grade carotid stenoses.1–3 This has created a requirement for accurate imaging of carotid disease to allow the precise measurement of stenosis severity. It is known that carotid atheroma is frequently eccentric4 and that the accuracy of stenosis measurement may be limited by the use of 2D imaging techniques.5–8 For this reason, 3D imaging techniques, including magnetic resonance (MR) angiography and CT angiography, have been suggested as the optimal form for the imaging of extracranial carotid disease.9–14 The purpose of the present study was to use CT angiography to determine the frequency of eccentric lumens in patients with significant carotid atheroma and to evaluate the effect that noncircular lumens have on stenosis measurement determined from angiographic reconstructions.

Subjects and Methods
One hundred consecutive internal carotid arteries in 74 patients were included in the present study. In each artery, there was at least a 50% stenosis as determined by Doppler ultrasound, with a range of 55% to 95%. All patients subsequently underwent spiral CT angiography as part of a routine preoperative workup.

CT angiography was performed according to a standardized protocol using a GE CTi scanner (GE Medical Systems). Ninety milliliters of nonionic contrast (300 mg iodine per milliliter) was injected at 4 mL/s with a time delay of 15 seconds during a spiral acquisition from C2 to C6. Three-millimeter sections at a pitch of 1.5:1 were obtained and were transferred to an independent workstation (GE Advantage Windows, GE Medical Systems) for data analysis.

The axial images at the level of maximal luminal stenosis were selected and were viewed with standard window settings of window level 200 and window width 850. The luminal shape was classified as circular or noncircular. Noncircular profiles included elliptical and linear luminal shapes. In patients with noncircular lumens, the orientation of the lumen in the transverse plane relative to the anteroposterior plane was determined by using workstation software. Oblique orientations toward the same side as the artery (ie, toward the right within the right carotid artery) were arbitrarily assigned positive values, whereas reverse oblique orientations were assigned negative values. An example of luminal obliquity measurement is illustrated in Figure 1. In each case, the head was positioned as straight as possible, but it is likely that a small degree of error was introduced on occasion by head inclination away from a strict anteroposterior plane.
In patients in which a noncircular lumen was observed, maximum intensity projection (MIP) angiographic reconstructions were obtained in anteroposterior, lateral, and 45° oblique planes; these are the projections used in standard angiographic practice at our institution. Standardized window settings of window level 200 and window width 500 were used. In addition, an angiographic reconstruction was obtained in a plane depending on the observed luminal obliquity to optimize the demonstration of the stenosis. The North American Symptomatic Carotid Endarterectomy Trial (NASCET) value was calculated from the MIP angiograms by comparing the diameter of the stenosed segment with that of normal more distal internal carotid artery beyond the bulb where the walls become parallel.\textsuperscript{1,15} Measurements were made only after scrutiny for collapse or attenuation of the distal internal carotid diameter to minimize fallacious ratios. These calculations were performed by a single neuroradiologist blinded to the Doppler and axial CT findings. In each case, the calculated stenoses from the anteroposterior, 45°, or lateral projections and from the optimized projection were compared. Measurements were obtained on 2 separate occasions by the same observer, and intraobserver variability was assessed by using the intraclass correlation coefficient.

**Results**

Eighteen patients were found to have noncircular luminal profiles in the transverse section, with the angle of luminal obliquity ranging from $+90^\circ$ to $-87^\circ$ (Figure 2). In 11 of these 18 patients, the luminal obliquity was in the reverse oblique direction.

The comparison between NASCET stenosis measurement as determined by our standard projections (anteroposterior, lateral, and 45° oblique) and by the optimized oblique projection is illustrated in Figure 3. In 2 patients, comparison of MIP angiograms was not possible because of the difficulty of including the distal internal carotid artery and the stenotic...
segment on the same reconstruction plane. The NASCET stenosis was greater in 11 (69%) of 16 patients on the optimized angiographic reconstruction, with a range of difference of 1% to 7%. An illustrative example is demonstrated in Figure 4. The difference was most notable in those patients with lumens orientated in the reverse oblique direction, as demonstrated in Figure 5. In 2 patients, stenosis measurement in the optimized oblique plane upgraded the stenosis from a moderate to a severe stenosis, as defined by NASCET criteria.

The intraclass correlation coefficient for intraobserver variability was 0.994 and was found to be very highly significant.

Discussion

Atherosclerotic stenotic disease of the extracranial internal carotid artery is well established as a major risk factor for subsequent thromboembolic cerebrovascular events. Several major multicenter studies have established carotid endarterectomy as an effective means of reducing risk in those patients with high-grade stenosis. Therefore, there is a need for an imaging strategy that can accurately determine and quantify the degree of vascular stenosis. For this reason, angiographic projections are usually necessary for the comparison of the diameter of the stenosed internal carotid artery with that of the normal distal internal carotid artery (NASCET) or with the estimated width of the carotid bulb (European Carotid Surgery Trial [ECST]). Catheter, MR, and CT angiography are conventionally used to provide angiographic representation of disease.

CT angiography is a well-established technique for imaging atherosclerotic disease of the extracranial carotid artery, with well-defined sensitivities and specificities for detection of surgical lesions. Interrogation of axial source data are an essential part of the CT angiographic examination, and it is recognized that stenosis grading is most reliable when it is based on measurements obtained from axial images. Axial images provide a cross-sectional view of the carotid artery and distinguish between residual lumen and surrounding atherosclerotic disease.

Figure 5. Plot of difference between NASCET stenosis calculated on anteroposterior, 45°, or lateral projection and optimized projection against angle of luminal orientation. The greatest error was observed with reverse oblique lumens (maximal at \( \approx -45^\circ \)).
plaque. The excellent soft tissue contrast and high spatial resolution inherent to the axial images allow the direct visualization of the plaque, and CT angiography has been proposed in a number of studies as an effective method for the demonstration of plaque morphology. In a similar way, the difference in attenuation between contrast within the diseased vessel and the surrounding plaque allows the morphology of the stenosed lumen to be analyzed in transverse section from the axial source data. This information is important because in the case of noncircular lumens, angiographic projections must be obtained in the exact transverse plane of the maximal cross-sectional stenosis to be accurate. In the case of a noncircular lumen, any projection that is not in this optimal plane is likely to have a degree of inaccuracy introduced. At our institution, it is standard practice to obtain angiographic projections at 0°, 45°, and 90°; therefore, it would be expected that any vessel with a noncircular lumen lying in a plane other than 0°, 45°, or 90° would not be accurately graded according to NASCET or ECST measurements obtained in these angiographic projections. In addition, any error introduced into NASCET or ECST calculations would be likely to be greatest in vessels with reverse oblique luminal orientations, maximally at 45° reverse oblique. It should be noted that the standard angiographic projections used in our practice may not be those used at other institutions and that a greater number of oblique and craniocaudal projections may be used by other operators. However, this fundamental principle remains valid in all cases examined with a finite number of 2D planes.

We observed a noncircular transverse luminal profile within the most stenotic part of the diseased vessel in 18% of the patients. Of these, 11 (61%) of 18 patients had lumens orientated in the reverse oblique direction.

The NASCET stenosis measurement was greater in 11 (69%) of 16 patients on MIP angiograms obtained in the plane optimizing the luminal stenosis than on MIP angiograms obtained in anteroposterior, 45° oblique, or lateral projections. The greatest error was observed in those patients in whom the lumen was orientated in the reverse oblique plane, most particularly with orientations close to a 45° reverse oblique orientation. Assuming that there would be no error on projections with luminal orientations at 0°, 45°, and 90°, a theoretical plot of induced error and luminal obliquity based on the observations in the present study would appear as in Figure 6.

In the present study, the grading of stenosis was upgraded from moderate to severe in 2 patients by use of optimized MIP angiographic projections. Although luminal obliquity did not have a significant effect on stenosis grading in the majority of patients in the present study, it is likely that it may be a significant cause of error in a minority of patients, particularly in those patients with a borderline grade of stenosis. This observation may also to some extent explain why conventional catheter angiography and use of standard imaging planes is associated with a tendency to underestimate the degree of carotid stenosis.

The implications of the present study for carotid imaging are as follows: First, it is arguable that conventional catheter angiography should routinely include a reverse oblique projection, particularly in cases of moderate carotid stenosis. Second, it confirms the importance of obtaining angiographic projections in multiple planes in 3D imaging modalities and supports the routine use of 3D imaging, whether MR angiography, CT angiography, or rotational catheter angiography is used for the imaging of extracranial atherosclerotic disease.

In summary, elliptical or linear vessel lumens in patients with significant carotid atherosclerotic disease commonly occurred in our study population. In a significant proportion of these patients, luminal obliquity introduced a varying degree of error in NASCET measurements obtained on our standard angiographic projections. The greatest degree of error occurred for those measurements in which the lumen was orientated in the reverse oblique direction. These observations have important implications for the measurement of stenosis severity from angiographic projections.

References
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