Three-dimensional helical computerized tomography angiography in the diagnosis, characterization, and management of middle cerebral artery aneurysms: comparison with conventional angiography and intraoperative findings

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Object. Middle cerebral artery (MCA) aneurysms can be difficult to detect and characterize. The authors describe the utility and impact of helical computerized tomography (CT) angiography for the evaluation of aneurysms in this location, and compare this modality with digital subtraction (DS) angiography and intraoperative findings.

Methods. Two hundred fifty-one patients with suspected cerebral aneurysms underwent CT angiography. Two-dimensional multiplanar reformatted images and three-dimensional CT angiograms were examined by two independent readers in a blinded fashion. Results were compared with findings on DS angiograms to determine the relative efficacy of these modalities in the detection and characterization of aneurysms. Questionnaires completed by neurosurgeons and endovascular therapists were used to determine the impact of CT angiograms on aneurysm management.

Twenty-eight patients harboring 31 MCA aneurysms and 26 patients without aneurysms were identified using CT angiography. The sensitivity of CT angiography and DS angiography for MCA aneurysms was 97%; both techniques showed 100% specificity. In 76% of evaluations, the CT angiography studies provided information not available on DS angiography examinations. For the characterization of aneurysms, CT angiography was rated superior (72%) or equal (20%) to DS angiography in 92% of cases evaluated (p < 0.001). Computerized tomography angiography was evaluated as the only study needed for patient triage in 82% of cases (p < 0.001), and as the only study needed for treatment planning in 89% of surgically treated (p < 0.001) and in 63% of endovascularly treated cases (p < 0.001). The information acquired on CT angiograms changed the initial treatment plan in 24 (67%) of these 36 complex lesions (p < 0.01). The aneurysm appearance intraoperatively was identical or nearly identical to that seen on CT angiograms in 17 (89%) of 19 of the surgically treated cases.

Conclusions. Computerized tomography angiography has unique advantages over DS angiography and is a viable alternative to the latter modality in the diagnosis, triage, and treatment planning in patients with MCA aneurysms.

Key Words • cerebral aneurysm • helical computerized tomography angiography • digital subtraction angiography
has been shown to have moderate-to-high sensitivity and specificity levels for the detection of brain aneurysms. Raw images from the volumetric helical scan can be postprocessed on an independent workstation by using 3D volume rendering, which is a more advanced postprocessing algorithm compared with surface-shaded display and maximum intensity projection. Helical CT angiography with volume rendering has been shown to be accurate in the quantification of vascular dimensions and in the characterization of intracranial aneurysms.

Although CT angiography has several significant advantages over DS angiography, no detailed studies are available in which the performance of this technique has been examined in a large cohort of patients, all of whom have aneurysms at specific locations in the circle of Willis. The purpose of our study was the following: 1) to determine the ability of CT angiography compared with DS angiography to detect and characterize fully both the luminal and nonluminal components of MCA aneurysms compared with DS angiography in a large cohort of patients; 2) to determine the impact of information provided on CT angiography studies on patient triage between surgical and endovascular treatment options; and 3) to determine the impact on treatment planning once a treatment option has been selected.

Clinical Material and Methods

Patient Population

Patients presenting at our hospital between May 1997 and June 1999 with signs or symptoms suggestive of cerebrovascular aneurysm were selected by the referring physician to undergo CT and DS angiography. If the DS angiogram was negative and the CT angiogram was positive, surgical confirmation of aneurysm presence was required for inclusion to the study cohort. Signs and symptoms included headache, cranial neuropathy, SAH detected on noncontrasted CT scans, xanthochromia on lumbar puncture, or an incidental noted or suspected aneurysm on routine CT or magnetic resonance studies.

Two hundred fifty-one patients underwent CT angiography for suspected intracranial aneurysms during the study period; 33 (13%) of them were found to harbor a total of 36 MCA aneurysms. Five patients underwent CT angiography and magnetic resonance angiography only and were excluded from the group, leaving 28 patients with a total of 31 MCA aneurysms as the study population. Twenty-six individuals within the same cohort of 251 patients who underwent both CT and DS angiography and were found to have no aneurysm served as negative controls.

Patients’ ages ranged from 32 to 73 years, and there were 11 men and 17 women. Locations for the 31 aneurysms were as follows: 27 (87%) in the MCA bifurcation, three (10%) in the M1 segment, and one (3%) in the M2 segment. Within the study population, 13 (46%) of 28 patients presented with SAH, compared with 31% within the control population. The presence of blood in the subarachnoid spaces was not found to interfere with aneurysm detection, exclusion, or characterization on CT angiography (Fig. 1).

In 19 of 28 cases DS angiography preceded CT angiography, in three of 28 cases CT angiography preceded DS angiography, and in six of 28 cases both studies were performed on the same day. The mean time between DS and CT angiography studies was 8.5 days, with a mode of 0.5 days, and a median of 42 days.

A timing injection was performed in all patients, with a 20-ml bolus of contrast material injected at 3 ml/second, a 10-second upfront delay; 15 images were acquired with a 1-second scan and a 1-second interscan delay, at an 80-kV peak, and at 80 mA. The CT angiograms were obtained using a routine clinical helical scanner or a single detector helical scanner with a 1.5 pitch, 1-mm slice collimation, 1-second gantry rotation cycle, 0.5-mm reconstruction interval, and 9- to 13-cm slab thickness, depending on the patient’s head size.

The CT angiogram was performed using contrast material injected at a rate of 3 ml/second and a total volume of 145 to 175 ml; this was administered through a 22-gauge antecubital venous angiocatheter. Scan coverage was from the bottom of the anterior arch of C-1 to the top of the lateral ventricles. Parameters included a 120-kV peak, 280 to 300 mA, 18-cm field of view, 512 × 512 matrix. A standard low-noise, low-spatial-frequency “soft-tissue” kernel reconstruction algorithm was used with 180° linear interpolation.

All patients consecutively entered into the study underwent CT angiography. Two independent readers analyzed the CT angiography studies in a blinded fashion; each reader prospectively identified an aneurysm as definitely present or definitely absent. No confidence intervals or consensus reading were used. An aneurysm was defined as any saccular or fusiform outpouching of an artery with measurable dimensions in three orthogonal planes and, if saccular, a discrete neck. Infundibula and aneurysm blebs were not included in the study. Computerized tomography angiography has previously been shown to differentiate accurately between an aneurysm and infundibulum.

Both 2D and 3D images were used for image analysis. Single slices (2D) viewed in cine mode, and thick-slab 3D MPR images were used for all quantitation. Volume rendering was performed in near real-time by using a commercially available volume rendering workstation operating on a Silicon Graphics board. The 2D cine mode (window 1000, level 500) and 3D images (window 250, level 150) were used for aneurysm detection, characterization of arterial branching patterns at the neck, visualization of thrombus and calcification and their relationship to the aneurysm neck, exclusion of arterial incorporation, depiction of the spatial orientation and geometry of the aneurysm sac and neck, and to demonstrate the relationship of the aneurysm to local and regional bone anatomy.

Measurements were made using the internal caliper tool, which has a linear accuracy of ± 10% for measurements less than 2 mm, and ± 4% for measurements between 2 and 10 mm. Aneurysm sac measurements were made both in orthogonal planes and relative to the long and perpendicular long axes of the sac. Possible lesions detected in one plane were confirmed on the remaining orthogonal planes by use of a crosshair cross-reference tool.

Complete, systematic examination of single-lesion data sets consisted of generating 23 standard 3D views of the anterior and posterior intracranial circulations, and additional sagittal and coronal 2D curved oblique MPR images of the high cervical, petrous, and cavernous-supraclinoid seg-
ments of the internal carotid arteries. Additional free-form 2D and 3D images of the aneurysms were made as necessary. Hard copies of the 2D and 3D images were made by the readers for use by the reviewing endovascular therapists and neurosurgeons. All prints were made using a special printer.

Three-vessel or four-vessel, multiple-projection, biplane DS angiography was performed using the Seldinger technique (G.D., F.V., and Y.P.G.) at our institution. Oblique and 2 to 3 × magnification views were routinely obtained to clarify aneurysm anatomy; the matrix size was 1024 × 1024. Eight of the angiograms were performed at other institutions by using a similar method.

Aneurysm sac and neck sizes on DS angiography were defined using the largest sac or neck diameter; all measurements were made using a digital caliper on midarterial frames. Aneurysm sizes were defined as follows: very small, 5 mm or less; small, greater than 5 to 10 mm; large, greater than 10 to 25 mm; and giant, greater than 25 mm. All DS angiographic quantitation was performed using fractional millimeters in standard orthogonal projections that were corrected for differential magnification. Aneurysm dimensions were for patent portions of the aneurysm only. The DS angiography measurements were performed by an interventional neuroradiologist (R.J.) who used the pixel count method or the reference method described by Fernandez Zubillaga, et al.

For both CT and DS angiography studies, aneurysms in which the neck diameters were 4 mm or less were defined as narrow. Those with diameters greater than 4 mm, or diameters equal to or larger than that of the largest parallel sac, were called wide. An artery was defined as incorporat-

Fig. 1. Sample images demonstrating the ability of volume-rendered helical CT angiography to depict arterial incorporation, bone landmarks, and rupture site in a giant saccular aneurysm of the left MCA bifurcation. Upper Left: Axial non-contrasted CT scan revealing extensive subarachnoid blood in the right sylvian fissure, as well as intraventricular blood. Upper Right: Conventional angiogram demonstrating a giant saccular aneurysm, although the neck geometry and arterial branching pattern are not apparent. Lower Left: Superior-inferior view, 3D volume-rendered helical CT angiogram demonstrating a giant saccular aneurysm of the right MCA bifurcation. Both M1 branches arise from the proximal aspect of the sac (straight black arrows), not the parent MCA (white arrow), indicating complete incorporation. Note the bone anatomy, including the optic nerve canal (curved black arrow). Lower Right: A 3D image, craniocaudal projection, mediolateral angulation, demonstrating the rupture site (curved open arrow), incorporated anterior M1 segment, distal right M1 (white arrow), and relationship of the aneurysm sac to the greater sphenoid wing (large black arrow), optic nerve canal (short open arrow), and ophthalmic artery (short black arrow).
ed into the aneurysm if it arose from the neck or body of the lesion, rather than from the parent vessel.

All CT angiography data sets were processed and interpreted by two independent readers (J.P.V. and P.H.) who were blinded to clinical history and DS angiography findings. The DS angiography findings were interpreted independently by one of two interventional radiologists (G.R.D. or P.Y.G.) who were blinded to the results of the CT angiography studies.

Only the images from the DS and CT angiography studies of each patient, without written interpretive reports, were then comparatively evaluated by a second group of investigators (G.D., Y.P.G., N.M., and J.E.). This group included two interventional neuroradiologists and two neurosurgeons, who each independently graded CT angiograms as inferior, equal, or superior to DS angiograms in their ability to show specific aneurysm features clearly and unambiguously. These features included all three dimensions of the aneurysm sac, the aneurysm neck, the arterial branching pattern at the neck, the ability to confirm or exclude the incorporation of an arterial branch into the body or neck of an aneurysm, and the ability to detect and characterize the presence of mural calcium or thrombus. The reviewers reported the pre– and post–CT angiography treatment plans to determine the impact of CT angiography on management. The DS angiography and surgical results served as the gold standard for aneurysm detection and characterization. All aneurysms treated based on CT angiography information alone were confirmed using DS angiography or by intraoperative findings.

A coded questionnaire completed by each member of the second group of investigators documented the basis for the scores given for each modality in each patient. Respondents were required to indicate if CT angiograms provided erroneous or misleading information. The null hypotheses were as follows: 1) that CT angiography was equal to DS angiography in its ability to detect cerebral aneurysms; 2) that CT angiography and DS angiography are equal in their ability to characterize aneurysm features; 3) that there would be no impact of CT angiography results on treatment plans; and 4) that there would be no case that was treatable based only on CT angiography data. Data were analyzed using McNemar’s test of proportions, with 5% as the criterion for significance. Additionally, the chi-square contingency tests were performed to assess the homogeneity of proportions. The unweighted kappa statistic was used to assess interobserver agreement for the CT angiography data. All patients provided informed consent for invasive procedures, and institutional review board approval was obtained.

Sources of Supplies and Equipment

The Hi-Speed helical scanner and the Cti single detector helical scanner were purchased from General Electric Medical Systems, Milwaukee, WI, as was the DS angiography device. The contrast material (Omnipaque 350) was obtained from Nycomed, Inc., Princeton, NJ. The volumerendering workstation (Vitrea 1.2) was acquired from Vital Images, Inc., Minneapolis, MN, and the graphics board was purchased from Silicon Graphics, Inc., Mountain View, CA. The Codonics NP-100 printer was supplied by Codonics, Inc., Middleburg Heights, OH. The digital caliper (Mitutoyo Digimatic) was purchased from Mitutoyo, Inc., Aurora, IL.

### Results

The mean time required for CT angiography scanning, image transfer, and image analysis was 31 minutes. This included complete systematic postprocessing of single-lesion CT angiography data sets requiring 5 to 20 minutes (mean 16 minutes). The four-vessel DS angiograms required 25 to 45 minutes to perform (mean 35 minutes), and analysis of the DS angiograms required an average of 6 minutes. Injection delays in patients varied from 8 to 54 seconds. There were no procedural complications related to the CT or DS angiography studies.

Data on aneurysm size and shape are summarized in Table 1. The majority of lesions were saccular. Fifty-eight percent of aneurysms were less than 10 mm in maximal diameter, and more than one fourth of the lesions were less than 5 mm in maximal diameter. The smallest aneurysm in this study measured 2.2 mm anteroposterior × 2.3 mm transverse × 2.7 mm craniocaudal, with a 2.3-mm neck.

The sensitivity and specificity of both CT and DS angiography for MCA aneurysms was high. There was one false-negative finding on CT angiography for both readers; no false-positive studies were found. This false-negative report was on a patient with a large arteriovenous malformation and a flow-related small saccular aneurysm of the right MCA bifurcation and was a reader error. The specificity of CT angiography was therefore 97% (30 of 31) for both readers. The sensitivity of DS angiography was 97% (30 of 31), because of the patient in whom catheter angiograms were false negative and who subsequently underwent neurosurgical clipping of a 2.4-mm saccular MCA bifurcation aneurysm based on positive CT angiography results alone. The specificity of both CT and DS angiography was 100% for both readers. Four of the control patients without aneurysms had confirmed infundibula. The remaining cases that were negative on CT angiography showed no vascular abnormalities on DS angiography.

Overall, in 79% of cases, the CT angiograms contributed unique information not available on the DS angiograms. The comparative ability of CT and DS angiography to detect aneurysm features is shown in Table 2. The aneurysm neck, one of the most important features of an aneurysm with respect to endovascular treatment options, was not measurable on DS angiograms in 22% of cases (Fig. 2). In contrast, CT angiography provided aneurysm neck dimensions in all lesions detected. Neck sizes were validated as accurate at the time of craniotomy and neurosurgical clipping in the 14 surgically treated patients.

Mural calcification was seen on CT angiography in five (16%) of 31 of the MCA aneurysms, and in three of five of these cases the calcification was found to extend to the an-
eurysm neck (Fig. 3). Aneurysms exhibiting mural calcification or intraluminal thrombus ranged in size from 7 to 59 mm. On DS angiography we were able to detect calcium in only one single case, a very heavily calcified giant fusiform MCA aneurysm. We were unable to detect mural calcium with DS angiography in the remaining four cases. Mural thrombus was seen on CT angiography in four (13%) of 31 cases, and involved the aneurysm neck in all four. Digital subtraction angiography demonstrated thrombus in a single case, an extensively thrombosed, giant MCA aneurysm sac. Mural calcification and intraluminal thrombus were seen in combination in only two cases, in one giant and one large saccular aneurysm. As a combined total, when mural thrombus or calcification was present within an MCA aneurysm, it involved the neck of the lesion in 78% of cases (Fig. 4).

Arterial incorporations could be definitively confirmed or excluded on CT angiography in all cases. In contrast, we were able to exclude arterial incorporation on DS angiography in only 14 (45%) of 31 MCA aneurysms; the remainder were uncertain (Figs. 1–3). Arterial incorporations were found with an incidence of 19 (61%) of 31 MCA aneurysms on CT angiography (Fig. 1). The presence of arterial incorporation determined on CT angiography in patients in whom this condition was deemed not visualized or uncertain on DS angiography was later independently confirmed at surgery, or on attempted endovascular coil placement. Of the remaining 12 aneurysms with no arterial incorporation on CT angiography, seven of them were deemed uncertain on DS angiography but were confirmed not to have arterial incorporation at surgery or on attempted endovascular coil placement. Three of the 12 were confirmed to be unincorporated on DS angiography, and two of the 12 were identified as incorporated on DS angiography. Of these last two cases, one is being treated conservatively, and therefore the possibility of incorporation cannot be confirmed surgically at this time, whereas the other was a giant fusiform aneurysm in which the apparently discordant CT and DS angiogra-

### Table 2

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<th>Aneurysm Feature</th>
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<th>p Value</th>
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<td>all 3 dimensions of aneurysm sac</td>
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<tr>
<td></td>
<td>Total: 30</td>
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<td>neck size &amp; geometry</td>
<td>Yes: 17; No: 1</td>
<td>0.005</td>
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<td></td>
<td>Total: 25</td>
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<td>arterial incorporation into sac</td>
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<td>&lt;0.001</td>
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<tr>
<td></td>
<td>Total: 19</td>
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<tr>
<td>intraluminal thrombus or mural calc of sac</td>
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<td>0.08</td>
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<td>Total: 6</td>
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<td><em>Calc = calcification.</em></td>
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Fig. 2. Sample images demonstrating the ability of volume-rendered helical CT angiography to clarify the complex branching pattern in a small saccular aneurysm. **Upper:** Conventional angiogram fails to depict the neck of the aneurysm clearly and does not clarify the branching pattern or exclude the possibility of arterial incorporation; the carotid artery siphon mimics an aneurysm in this projection. **Center:** Posteroanterior projection CT angiogram demonstrating a saccular aneurysm (curved arrow), M₁ segment (short wide arrow), anterior, middle, and posterior M₂ divisions (long white arrows), and an early origin of an anterior temporal artery (small thin arrow). The middle cerebral vein complex is also visible (short open arrow). **Lower:** Detail view, craniocaudal projection, clearly demonstrating terminal M₁ (black arrow) and M₂ segments of arteries projecting toward the viewer (curved arrows), and bracketed aneurysm neck. Note the wide neck (thin arrows) and evidence of arterial incorporation; both M₂ branches arise from the sac of the aneurysm, not the parent artery. The anterior temporal branch is seen to wrap around the sac and continues distally (short white arrow). The wide neck and incorporations make coil treatment hazardous and arterial reconstruction difficult.

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phy findings reflected a definitional difference between the readers and not a discrepancy in anatomical visualization.

Twenty-three (74%) of the 31 patients with aneurysms in this study underwent treatment; the remaining eight did not undergo operation. Of the treated group, 14 (61%) of 23 were treated surgically, eight (35%) were treated endovascularly, and one patient (4%) was treated with combined surgical and endovascular methods. This patient had a giant fusiform aneurysm of the left MCA bifurcation (Fig. 4). Of the surgically treated aneurysms, 11 (79%) of the 14 were clipped, whereas two were treated with combined clipping and arterial bypass and one with bypass and aneurysm resection. These lesions were large saccular ones that had incorporated arterial segments, which required preservation of the distal arterial supply before aneurysm treatment with an EC–IC bypass.

Of the coil-treated aneurysms, the lesions’ neck sizes ranged from 3 to 5.6 mm (mean 4.56 mm), with dome/neck ratios of between 1.3 and 2.4 (mean 1.78). All of the embolized lesions with dome/neck ratios of less than 2 had calcifications or thrombus at the neck and thus represented a higher surgical risk. Of the aneurysms undergoing surgery, neck sizes ranged between 2.4 and 10 mm (mean 5.75 mm), with dome/neck ratios of between 1.1 and 5.1 (mean 2). Of the surgically treated lesions with dome/neck ratios greater than 2, in 71% arterial segments were incorporated, precluding safe coil treatment. In the remaining two cases the physician judged that either modality would be appropriate, and surgery was selected. There was no statistically significant difference between CT and DS angiography measurements of aneurysm sac size when orthogonal CT angiography projections were used and a spherical sac geometry was dominant (p > 0.05).

Eight (26%) of 31 cases were treated conservatively. We determined that one lesion was inoperable due to multiple incorporated arterial segments, and the remaining seven cases are being followed noninvasively by using CT angiography. In the patients treated conservatively the mean sac size was 5.5 mm and neck sizes ranged from 2.4 to 10.8 mm, with dome/neck ratios ranging between 1.1 and 2.2. One or more arterial incorporations were found in 80% of conservatively treated cases. Additional features common to conservatively treated cases included small aneurysm size, complex arterial anatomy, and asymptomatic patient status.

The information provided on CT angiograms caused the treatment plan to be changed in 20 (65%) of the 31 aneurysms evaluated. The effect of the CT angiography data on the treatment plan is shown in Table 3, which lists only those cases in which a change in treatment plan was registered after review of CT angiography data, compared with the treatment plan contemplated when relying on DS angiography information alone. In 11 (35%) of 31 evaluations, CT angiography data did not impact the treatment decision. In 14 (74%) of the 20 cases in which CT angiography results prompted a change in the treatment plan, the correct course of action was uncertain because of incomplete lesion characterization before CT angiography was performed. The most common reason for a plan change from coil treatment to surgery (25%) was the demonstration of a wide neck on CT angiography in cases in which the neck was not clearly visualized on DS angiography. The most common reason for a change from uncertain status to surgery (50%) was the demonstration of a wide neck or complex arterial anatomy which would preclude safe coil placement. The most common reason for a change from surgery to coil treatment was the demonstration of a wide neck or complex arterial anatomy which would preclude safe coil placement. The most common reason for a change from surgery to coil treatment was the demonstration of a wide neck or complex arterial anatomy which would preclude safe coil placement. The most common reason for a plan change from coil treatment to surgery (25%) was the demonstration of a wide neck on CT angiography in cases in which the neck was not clearly visualized on DS angiography. The most common reason for a change from uncertain status to surgery (50%) was the demonstration of a wide neck or complex arterial anatomy which would preclude safe coil placement.
was the demonstration of an incorporated artery in the sac or neck of a candidate aneurysm. The most common reason for a change from uncertain status to combined surgical or endovascular and surgical therapy after CT angiography was the demonstration of calcification or thrombus at the neck of an aneurysm. In two patients in whom the best treatment option was uncertain before CT angiography, the decision to treat with endovascular coil placement was made after CT angiography demonstrated a focus of calcification from a previously thrombosed aneurysm near the neck of an adjacent, unprotected lesion (Fig. 3). The reason for the change from uncertain to untreatable status was the demonstration of multiple incorporated arterial segments.

In the group of patients in whom surgery was the treatment of choice before CT angiography, the CT data changed the planned surgery in one case (5%). In this case the treatment was changed from a simple clipping procedure to one involving an arterial bypass with aneurysm clipping, because the CT angiograms demonstrated that calcification at the neck of the aneurysm would make primary clip occlusion hazardous, thus necessitating a more complex treatment solution.

In the remaining cases, CT angiograms confirmed rather than changed or contradicted the preprocedural surgical plan. In one patient for whom the planned procedure was uncertain before CT angiography was performed, the
Three-dimensional helical CT angiography for MCA aneurysms

The ability of the imaging method to provide complete lesion characterization is a crucial prerequisite in selecting the optimal treatment modality. In this study, we show that helical CT angiograms provide a sensitivity and specificity for aneurysm detection equal to DS angiography. We also show that CT angiography provides excellent characterization of aneurysm features that are important in treatment decisions and therapy planning. Complications related to MCA aneurysm treatment may result from both surgical and endovascular approaches. Morphological features that have been associated with unsuccessful endovascular coil treatment include a dome/neck ratio of less than 2, aneurysm neck larger than 4 to 5 mm, incorporation of major artery branches into the lesion wall, giant size aneurysms, and the presence of extensive intraaneurysm thrombus. For those aneurysms amenable to surgery, the preferred treatment is direct primary clip occlusion. Anatomical features related to poor surgical outcome in MCA aneurysms include laterally projecting lesions, larger size aneurysms, surgeries requiring complex approaches, bypass procedures, and vascular reconstructions. In our study, CT angiography data were estimated to have shortened operating room time in 11% (CT angiography revealed that a more complex procedure would be required), and to have caused no change in surgical time in 22%. The potential morbidity was estimated to have decreased in 56% of cases and to be unchanged in 44%.

### Discussion

2D and 3D images prompted changes in the treatment plan from simple clip occlusion to arterial bypass and aneurysm resection because of the demonstration of a wide neck and mural calcification of the sac extending to the neck region. In this patient, CT angiography also revealed the location and size of the donor STA.

The neurosurgeons in our group evaluated CT angiography as superior or equal to DS angiography in the characterization of the arterial branching pattern around the aneurysm neck in 96% of cases (Fig. 2). The aneurysm neck size and geometry were visualized as well as or better than on DS angiography in 96% of cases, and the presence of an arterial incorporation was visualized with equal or superior ability to DS angiography in 92% of cases (Fig. 1). These results are given in Table 4.

The endovascular therapists in our group evaluated CT angiography as equal or superior to DS angiography in the characterization of the arterial branching pattern around the aneurysm neck in 84% of cases, and equal or superior to DS angiography in 89% of cases with respect to visualization of the aneurysm neck size and geometry. Also, the CT modality was evaluated as equal or superior to DS angiography in 88% of cases in terms of exclusion of arterial incorporations (Table 4).

Computerized tomography angiography was found to be superior (72%) or equal (20%) to DS angiography in characterizing relevant aneurysm features in a total of 92% of the cases evaluated (p < 0.001). The ability of CT angiography to serve as the only imaging study prior to therapy, as judged by both neurosurgeons and endovascular therapists, is shown in Table 5.

The appearance of the aneurysm on CT angiography compared with its intraoperative appearance in the 14 surgically treated patients was identical in 84% and nearly identical in 5%. Major variations were found in two patients; in the first one, a middle cerebral vein branch was draped over the aneurysm, mimicking an artery. The second case involved a patient with multiple aneurysms, all confirmed on both CT and DS angiography, in whom a 2.7-mm right MCA aneurysm was not treated intraoperatively, because larger aneurysms on the contralateral side were suspected to have been the source of bleeding. If this case is not included in the calculations, then the percentage of cases in which the aneurysm appearance at surgery was identical or nearly identical to CT angiography findings climbs to 93%.

The CT angiography data were estimated to have shortened operating room time in 67% of cases (compared with the same surgery performed relying on catheter angiography information alone), to have lengthened operating room time in 22%. The potential morbidity was estimated to have decreased in 56% of cases and to be unchanged in 44%.

### Analysis of 20 patients whose treatment plan was changed after CT angiography*

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<th>Plan Pre-CT</th>
<th>Plan Post-CT</th>
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<td>total</td>
<td>53 20 3</td>
<td>76 87</td>
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* Endo = endovascular; NA = not applicable.

### Characterization of aneurysm features on CT compared with DS angiography*

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<th>Aneurysm Feature</th>
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<th>Subtotal</th>
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<td>19 4</td>
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<td>neck geometry</td>
<td>11 6 2</td>
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<td>3 20</td>
<td>0.01</td>
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<td>7 16</td>
<td>&lt;0.001</td>
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<tr>
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<td>66 49</td>
<td>&lt;0.001</td>
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### Opinions on ability of CT angiography to serve as the only imaging study before therapy of MCA aneurysms

<table>
<thead>
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<th>Physician</th>
<th>Response</th>
<th>Total</th>
<th>p Value</th>
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<tr>
<td>endovascular therapist</td>
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<tr>
<td>total</td>
<td>41 9 50</td>
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ography was superior to DS angiography in the demonstration of these features in 72% of cases and equal in 20%. When direct clipping is not possible, surgical alternatives include proximal occlusion with arterial bypass, gauze wrapping of the aneurysm sac, or vascular occlusion of the parent artery without a bypass procedure. The rationale for these complex procedures is to safeguard the arterial blood supply by bypassing the site at risk, and then proceeding with definitive treatment of the offending lesion. In the same data set, CT angiography also demonstrates the size and location of the STA (Fig. 4) or occipital artery for possible bypass.

In our study, there was one false-negative result on a CT angiography study that was a reader error, and one false-negative result on a DS angiography study that was due to an inability to obtain the optimal angiographic projection in a patient with a complex bifurcation. The false-negative CT study is a reminder that, under appropriate conditions, all MCA aneurysms should be detectable on CT angiography, and underscores the fact that diligent examination of the source images is crucial to treatment success.

The sensitivity and specificity rates of CT angiography in this study are higher than previously reported in the literature, but comparable to those reported in more recent publications, and in some older studies as well. We believe that the reason for the difference in sensitivity and specificity is the progressive interval improvements in acquisition and postprocessing protocols and optimized image review protocols.

Previous studies have generally used earlier versions of image acquisition protocols and postprocessing workstations with software that is suboptimal compared with the protocols and technology currently available. An example of persistent problems related to acquisition protocols is the recently published article by White, et al., who used a small total injection volume, a lower concentration of non-ionic contrast material (Iopamidol 300 compared with 350) and whose study lacked a patient-specific injection delay. The use of empirical injection delays results in suboptimal intravascular contrast opacification in up to 70% of patients when delays of 18 to 20 seconds are used, as in the earlier case. Although in some centers a fixed injection delay is used for all CT angiography studies, we recommend performing a timing study to determine a precise delay for each patient, or the use of bolus detection software. The performance of a timing run helps to optimize image quality by ensuring peak contrast opacification during helical scanning.

An analysis of the significant differences in our postprocessing protocol compared with previous studies in which the utility of CT angiography for detection of brain aneurysms was reported also reveals several important features. We used volume rendering, which can display helical data by using multiple levels of opacity, color, surface contrast, and perspective. Surface-shaded display and maximum intensity projection image-rendering methods, which were previously the most commonly used for image rendering, have been shown to be inferior to volume rendering in the visualization of key aneurysm features because they use simple schemes to distinguish vessels from other tissues. True anatomical spatial relationships are better visualized with volume-rendering methods, and volume rendering provides a clearer visualization of vascular relationships and of tissues with different compositions. Another limitation of earlier studies is the underutilization of the multiplanar source images and free-form interrogation of the image data. The consistent use of the cross-referencing tool on the axial 2D source data to confirm a suspected abnormality on the sagittal and coronal MPR images is also a crucial step in confirming or excluding a suspected lesion. This is particularly important in the MCA bifurcation and cavernous sinus regions. Approximately 10% of the aneurysms in this study were identified initially on 3D images and only retrospectively on the 2D images by both readers, emphasizing the importance of systematic inspection of the 3D image data. Consistently high-quality CT angiography can be performed at any institution with a single or multiple detector helical scanner by using optimized acquisition protocols that are tailored for neuroimaging applications and that emphasize high spatial resolution, and by using a high-quality commercially available postprocessing system.

Accurately measuring the size of an aneurysm neck can be a challenge on DS angiography, because with this modality there is no inherent image scale. True dimensions must be extrapolated from reference values for the supraclinoid internal carotid artery obtained from the literature. These reference values represent population means that are then used to calculate aneurysm dimensions. This approach has several disadvantages. Although there were no statistically significant differences in aneurysm sac and neck sizes overall (p > 0.05), measurement discrepancies were apparent when an elliptical geometry was dominant (Cases 4, 9, and 11). In these patients, conventional angiography was found to underestimate the long axis while overestimating the short axis. This difference was significant for larger aneurysms if the largest sac dimension was parallel to the neck. Reports indicate that in up to 11% of DS angiography studies the aneurysm neck cannot be measured accurately because of irregular sac morphology, superimposition of normal arteries over the neck region, or absence of the appropriate angiographic projection. In our study the aneurysm neck could not be measured on DS angiography in 22% of cases.

In general, the aneurysms in this study were treated according to the selection guidelines suggested in previous publications. There were several exceptions, which can be explained on the basis of unique anatomical or clinical considerations. For instance, most of the aneurysms with dome/neck ratios of less than 2 that were embolized with detachable coils had calcifications or thrombus at the neck that rendered them unsuitable for primary clip occlusion. Of the surgically treated aneurysms with dome/neck ratios of less than 2, five (71%) of seven showed incorporated arterial segments. In the remaining two cases the physician judged that either modality was adequate, and surgery was selected. Two other exceptions occurred when coil placement was attempted in two patients with borderline anatomy, but in whom surgical clip occlusion was ultimately performed, as CT angiography findings initially indicated would be necessary.

Computerized tomography angiography was assessed as being the only study necessary prior to treatment in 89% of neurosurgical and in 46% of endovascular evaluations. Broken down by specialty, neurosurgeons had sufficient information with CT angiography data to proceed with sur-
gery in the majority of cases. In two cases DS angiography was necessary: one was a patient who potentially required a neck vein graft, necessitating visualization of this non-cranial vascular anatomy, and the other was a patient with complex anatomy in whom confirmation of aneurysm neck size on DS angiography was desired. Digital subtraction angiography was required in addition to CT angiography when the criteria for coil treatment included obtaining hemodynamic information about intraaneurysmal flow patterns and stasis. In two cases DS angiography was performed as part of an attempted coil placement procedure, which failed. These patients had small saccular lesions in which CT angiography indicated that a branch arose from the aneurysm neck region, suggesting that coil treatment would be hazardous, but the interventional procedure was nevertheless undertaken to confirm that an endovascular approach would be impossible in practice.

After review of the CT angiograms, the treatment plan was changed in 67% of patients evaluated using DS angiography. These large percentages reflect the generally complex nature of aneurysms included in this study group, and is a reflection of the referral patterns commonly encountered in a tertiary care facility such as ours, in which there is special emphasis on treating neurovascular disorders. In up to 42% of cases the appropriate treatment was uncertain on DS angiography findings prior to CT angiography. This was generally because the neck geometry or possible arterial incorporations could not be determined or confirmed on conventional angiography (Figs. 1 and 2).

In 46% of patients with positive results and in 31% of patients with negative results on CT angiography there was hyperdense blood in the subarachnoid spaces (Fig. 1). The presence of blood in the subarachnoid space was not found to interfere with aneurysm detection or characterization on CT angiography, in contrast with early studies. Our findings are in agreement with more recent reports.

As a technique, helical CT angiography has a number of limitations. The most important is the inability to visualize very small arteries consistently. Although this may not be a significant consideration for MCA bifurcation aneurysms, in which very slender MCA branches or other important vessels are rarely seen, aneurysms in the M segment may incorporate lenticulostraliate arteries that may be below the detection threshold of routine CT angiograms. When an aneurysm is suspected to incorporate one of these very small vessels, a DS angiogram must be performed before treatment to avoid unintended occlusion of an important small perforating vessel. Additional potential limitations of this technique include an inability directly to visualize distal collateral flow between vascular territories because of the small size of many of these collateral vessels, a general but not universal inability to show flow patterns within an aneurysm because of short intracranial circulation time relative to total scan time, and simultaneous visualization of arterial and venous phase imaging for the same reason. In our experience, visualization of veins in conjunction with arteries can assist with surgical planning. Veins opacified with contrast material are generally less dense than arteries, and can be made to recede or disappear on the 3D image simply by changing the window and level settings. Rarely, a prominent vein can interfere with image interpretation, which occurred in one case in which a vein adjacent to an aneurysm sac was misinterpreted as an artery.

This prospective study has a number of limitations. These include the probable introduction of a selection bias arising from the fact that our referral base causes our caseload to be heavily weighted toward difficult aneurysms. This bias has the effect of selecting for study those patients most likely to benefit from CT angiography, thus potentially falsely elevating the apparent utility of the technique. Increasing the sample size and adding more centers, including those treating a larger number of simple aneurysms, may help to control for selection bias. On the other hand, the fact that CT angiography performs well in this setting indicates that this modality is uniquely suited to handle even the most complex cases when the appropriate acquisition and processing protocols are used. An assessment bias may also have been introduced because we did not use a magnitude scale in our questionnaire. A consequence of this approach is that if one technique is judged to be superior to another, it is not clear if the superiority is marginal or considerable. Our use of figures in this manuscript serves to mitigate that limitation visually by allowing the viewer to experience the differential characterization ability of each modality, while providing a demonstration of the consistently high image quality possible with currently available postprocessing software.

Conclusions

Computerized tomography angiography has a sensitivity and specificity for MCA aneurysms that is equal to those of DS angiography. More importantly, when compared with DS angiography, CT angiography is its equal or superior in the characterization of aneurysm features in most cases. This information is crucial for selecting the optimal treatment modality. We believe that CT angiography is currently an appropriate triage and treatment planning tool in the overwhelming majority of surgically treated, and a small majority of endovascularly treated patients with suspected MCA aneurysms. The additional information contained in CT angiograms changed the treatment plan in up to 65% of complex cases.

References


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