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LEARNING OBJECTIVES

Upon completion of this activity, participants should be able to:

- Describe CT imaging protocols typically used for the screening of intracranial aneurysms.
- Explain the postprocessing methods available for visualization of CT angiography data sets.
- Summarize the results of comparison studies of CT angiography with gold standard digital subtraction angiography in screening for intracranial aneurysms.
- Describe how complications of aneurismal rupture can be imaged using CT.

Who will benefit:

Physicians, physician assistants, nurses, and radiologic technologists will benefit from the information in this educational activity and can receive Continuing Medical Education credit by completing the post test and evaluation provided.

Modern multislice CT imaging of intracranial aneurysms

By Max Wintermark, M.D., and Sarah Schaeffer, MPH

Over the last decade, CT angiography has increasingly been used for the early diagnosis and detection of ruptured intracranial aneurysms,[1-7] and most recently for the detection and treatment planning of nonruptured aneurysms.[8-12] The current accepted gold standard imaging modality for the evaluation of suspected aneurysms is digital subtraction angiography; however, DSA is an invasive study with a small but significant 4% risk of complication[13,14] and 0.07% to 1% reported risk of persistent neurological deficit.[13,15]

CTA provides a much desired noninvasive method of intracranial angiography that allows for multiple techniques of 2D and 3D viewing, including multiplanar reformation (MPR), maximum intensity projection (MIP), shaded surface display (SSD), and direct volume rendering (dVR).

The recent introduction of multidetector-row CT has allowed great advances in CTA imaging. Compared with single-section CT scanners, multislice CT scanners offer faster speed, longer distance, and thinner slice thickness as well as volumetric acquisition with considerable improvement in quality and spatial resolution.[16,17] MSCT systems have evolved from four- to 16- and now 64-channel detector row scanners. With the increase in the number of detectors, partial volume effect can likely be reduced due to more isotropic voxel data being available, further increasing the quality of CTA images.[10]

Advances in MSCT scanning have significantly improved the ability of CTA to identify and characterize intracranial aneurysms, as compared with DSA, possibly allowing

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CTA to replace DSA as the preferred method for imaging aneurysms.

CTA IMAGING PROTOCOLS FOR INTRACRANIAL ANEURYSMS

At our institution, the typical CTA protocol used on our 64-slice CT scanner (Lightspeed VCT; GE Medical Systems, Milwaukee) in patients with suspected or known intracranial aneurysm is as follows: spiral mode, 0.4-second gantry rotation time, detector collimation of 64 x 0.625 mm, pitch of 0.984:1, 0.625-mm slice thickness, 0.5-mm reconstruction interval, and 120 kVp/240 mA acquisition parameters. A caudocranial scanning direction is selected, covering the whole brain down to 1 cm below the foramen magnum, in order to encompass the posterior inferior cerebellar arteries in the volume analysis. Seventy milliliters of iohexol (Omnipaque, Amersham Health, Princeton, NJ; 300 mg/mL of iodine) are administered into an antecubital vein using a power injector at an injection rate of 5 mL/sec.

CTA protocols for intracranial aneurysms reported in the literature are very similar. The main variations relate to the amount of contrast administered and the injection rate and to the method used to obtain proper timing of the CTA acquisition with respect to the injection of contrast. To achieve appropriate timing of the CTA acquisition, we typically use a test bolus technique, while others use a bolus tracking technique or precalculated standard delay time.

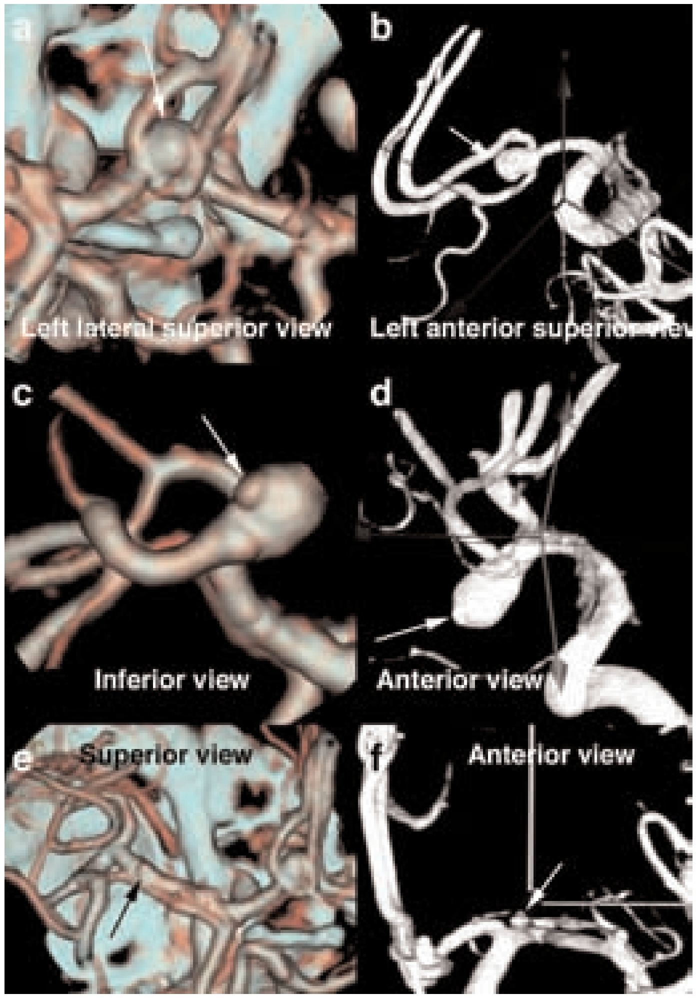


FIGURE 1. 56-year-old female patient with unusual headaches but no subarachnoid hemorrhage. CTA 3D SSD views (a,c,e) and 3D DSA (b,d,f) both correlate in demonstration of 4-mm left anterior communicating artery aneurysm (sac/neck ratio of 1 to 1.4, arrows) (a, b) and an 8 x 5-mm aneurysm at right sylvian bifurcation (sac/neck ratio of 1 to 1.4) (c,d), showing small accessory inferior lobulation (arrows). On the other hand, 3D DSA (f), but not conventional DSA, depicts 1.5-mm aneurysm on superior aspect of left M1 segment (arrow). Aneurysm (e) was visible on admission CTA as very tiny outpouching (arrow) but prospectively considered as an arterial wall irregularity rather than as a true aneurysm by the two reviewers.

VISUALIZATION METHODS

One advantage of CTA is that several postprocessing methods are available for both 2D and 3D visualization, including MPR, MIP, SSD, dVR, and endoscopic mode. Each method provides different advantages for reviewing CTA images (Figures 1 through 3).

- *Multiplanar reformation.* MPR allows for the creation of reconstructed images from any angle or plane with a defined depth of volume. In contrast to MIP, SSD, and dVR, MPR has the advantage of being able to include all information from source images in the reconstructed images. MPR is the easiest way to analyze volumetric data and is helpful as the method of first choice for the examination of CTA data.[18]

- *Maximum intensity projection.* With MIP, only the brightest voxels of a volume from any given angle are collected and used to create an image.[19] MIP involves collapsing voxels from different volumes into one plane, giving 2D images. Depth information is often lost, making it difficult to tell the orientation of a structure based on a single MIP image. MIP does have the advantages of being able to avoid any thresholding selection and to differentiate calcium from vascular contrast enhancement.[20,21] It is also relatively easy to use. MIP is most helpful in the analysis of intracranial aneurysms when used interactively in thin sections in combination with MPR.[22]

- *Shaded surface display.* SSD provides 3D visualization of CTA images and requires the user to define upper and lower thresholds for the selected voxels depending on their attenuation. SSD provides valuable information about the 3D shape of an object, but because all structures are shown in the same color, information about each structure's attenuation is lost. For this reason, it is not possible to distinguish arterial calcifications on SSD images. Using SSD and MIP concurrently may give the best information about 3D shape of intracranial aneurysms.[11]

- *Volume rendering.* Direct VR is the most sophisticated method of 3D visualization. It selects several groups of voxels according to their attenuation and assigns them a color and opacity.[23,24] VR is not subject to loss of information like MIP or loss of attenuation as with SSD, and it has the ability to distinguish bone from vasculature. It is, however, depend-

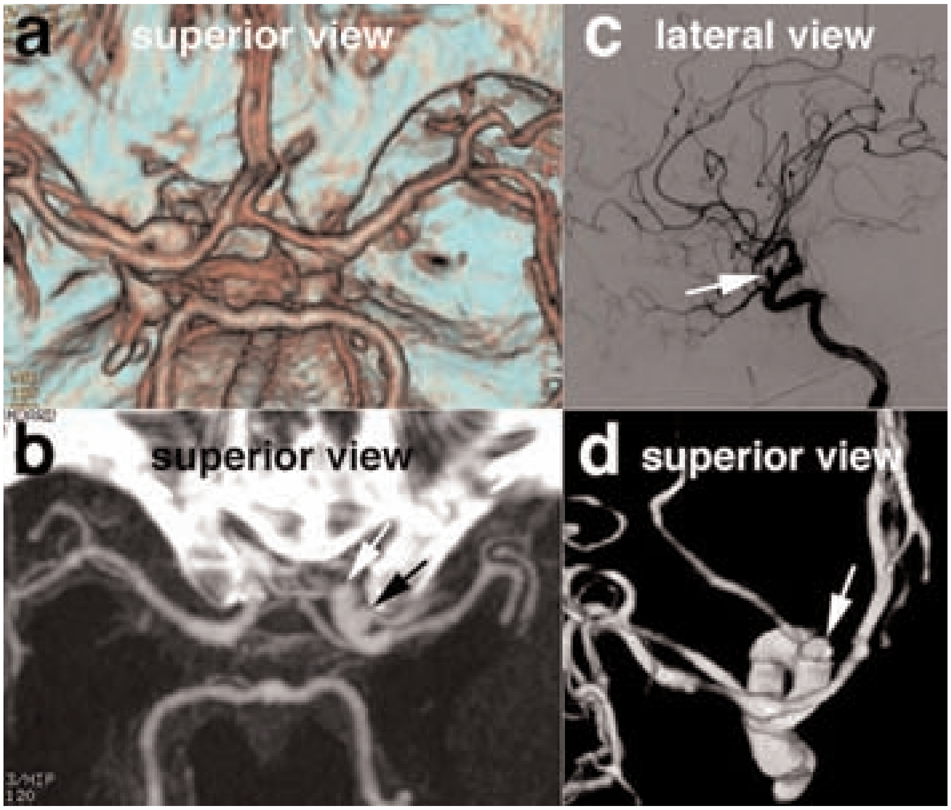


FIGURE 2. 63-year-old male patient. On CTA (a), especially on MIP (b), left deep middle vein (black arrow) creates confusing pattern. Aneurysm was identified in its correct location by one of the reviewers only, whereas the other reviewer confused it with left deep middle vein and described it as paraclinoid. DSA (including 3D DSA) (c,d) demonstrates 3-mm aneurysm located at origin of left ophthalmic artery (white arrows), with sac/neck ratio in range of 1 to 1.4.

ent upon many variables such as user experience, the quality of the postprocessing workstation, and the applied rendering algorithm.[24]

- *Endoscopic mode.* In cases where nearby bony structures make it difficult to evaluate a potential aneurysm, using the endoscopic mode with CTA imaging may provide clarification. The endoscopic mode makes it possible to more clearly delineate the relationship of the aneurysm to neighboring bone structures, adjacent veins, parent arteries, and structures at the skull base.[25] Knowing the precise location of these potential obstacles in relation to the aneurysm(s) can make CTA invaluable in planning treatments and surgical procedures.

CTA VERSUS DSA IN DETECTING INTRACRANIAL ANEURYSMS

A previous review of studies published between 1988 and 1998 demonstrated CTA to have an average sensitivity of about 90% for the detection of intracranial aneurysms, with aneurysms ≤3 mm being detected in 61% of cases, and higher sensitivity (up to 96%) for larger diameter aneurysms.[26]

More recently, studies published between 2004 and 2007 reported sensitivities of 89% to 94% on a per-aneurysm basis and 86% to 100% on a per-patient basis.[8-10,12,27,28] The highest sensitivities were reported in studies using DSA as a gold standard for comparison.[10,12] In one study using surgery as the gold standard of reference, CTA was found to have a sensitivity equal to that of DSA on a per-aneurysm basis (88.7% versus 87.8%, respectively). Corresponding specificities of these studies were reported as 93% to 100% on a per-aneurysm basis[9,10] and 88% to 93% on a per-patient basis, with reported accuracies of 92% to 98%.[9,10,12] Observer experience has been shown to be critical in the successful evaluation of images acquired with CTA.[8,29]

The success of CTA in detecting intracranial aneurysms is strongly dependent on aneurysm size. In recent studies, its reported sensitivity for small aneurysms (<3 to 4 mm) ranged from 67% to 84%, while the sensitivity for aneurysms larger than 3 mm was 93% to 100%.[8-10,12] Typically, aneurysms of the posterior communicating artery have proven difficult to diagnose with CTA and often are missed or mistaken for infundibular dilations.[9,12] Aneurysms that are located near bony structures, are attached to the posterior clinoid process, or demonstrate a "kissing vessel" artifact have also proven difficult to diagnose on CTA.[10,11,29,30]

CTA has, however, shown 100% sensitivity in detecting aneurysms in the anterior communicating artery and middle cerebral artery bifurcation, regardless of aneurismal size.[3,9,31] CTA also has an acceptable sensitivity for the diagnosis of aneurysms responsible for subarachnoid hemorrhage, although DSA is still required with negative CTA because of its poor negative predictive value.[32]

IMPACT OF CTA IMAGING ON TREATMENT

One major advantage of DSA is the ability to avoid venous contamination on imaging. Although faster multidetector-row scanners may be able to accomplish pure arterial phase CTA,[33] often depiction of venous structures cannot be avoided. This feature of CTA may actually serve as an advantage, however, since information regarding nearby vasculature can play an important role in treatment planning.

Another major advantage of CTA is the ability to depict neighboring bone structures, which has been demonstrated to be of great value in treatment and surgical planning.[34] Finally, CTA can be performed immediately after conventional CT, which is extremely advantageous in the emergency setting.

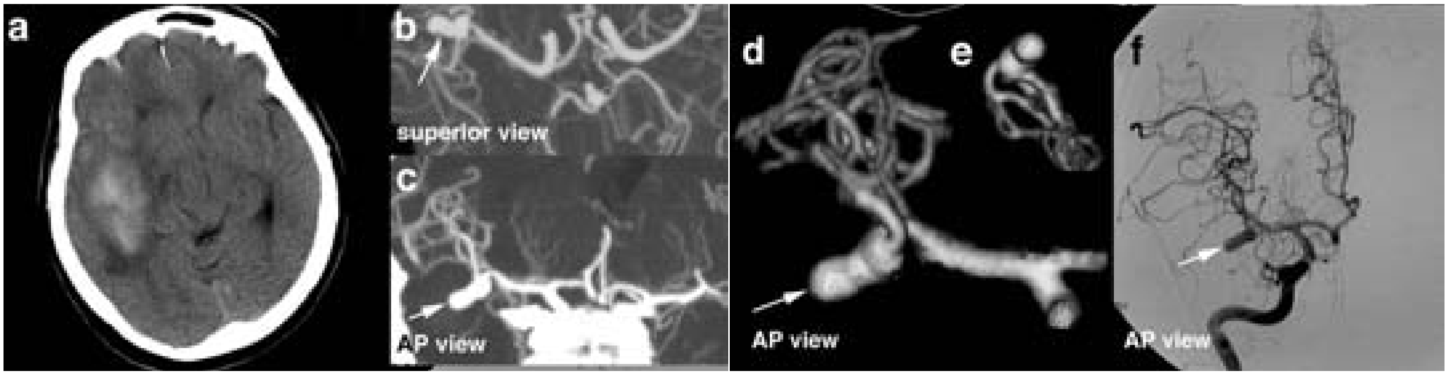
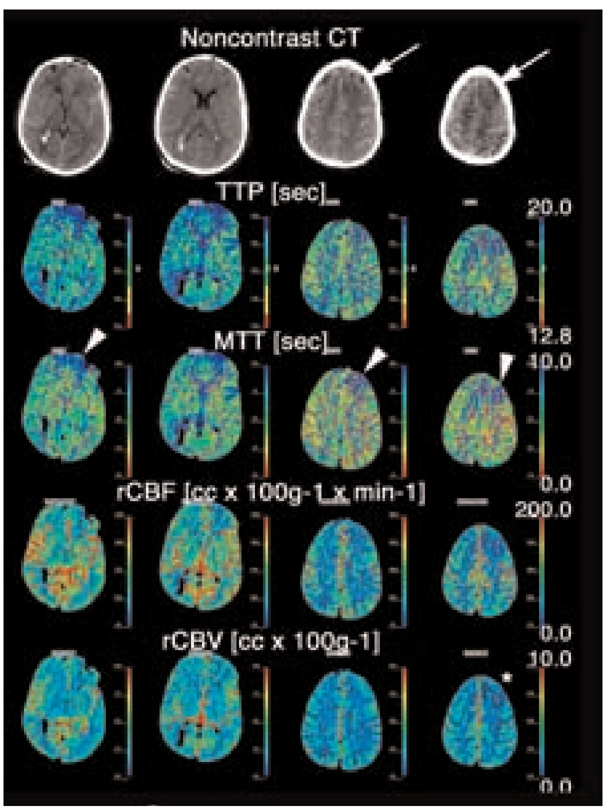


FIGURE 3. 71-year-old female patient (a) whose admission noncontrast cerebral CT demonstrates a right frontoparietal parenchymal hematoma, associated with subarachnoid hemorrhage. Excellent correlation between CTA, MIP (b,c), VR (d,e), and IADSA (f) views, which demonstrate giant dysplasic aneurysm of right sylvian bifurcation (arrows) in exactly similar way. This aneurysm measures 25 x 10 mm. Its sac/neck ratio is in the range of 1 to 1.4. Aneurysm is oriented laterally, as well as somewhat anteriorly and inferiorly. No arterial branch originates from aneurysm.

CT FOR COMPLICATIONS FOLLOWING ANEURYSM RUPTURE

In patients with aneurysmal subarachnoid hemorrhaging, the risk of vasospasm poses a major threat. Vasospasm occurs with a prevalence as high as 70% in the first two weeks following subarachnoid hemorrhaging,[35] and it represents the leading cause of death and disability in patients who survive the initial hemorrhagic event.[36] Early recognition and treatment of vasospasm can greatly improve the neurological outcome.[37-39] CTA has previously been reported to have a sensitivity of 64% and specificity of 96% in assessing the presence or absence, location, and severity of vasospasm after subarachnoid hemorrhaging.[40,41]

Recently, we investigated the potential of CTA combined with perfusion CT to represent a noninvasive alternative to DSA for detection of vasospasm after subarachnoid hemorrhaging.[42] This study demonstrated an excellent correlation of



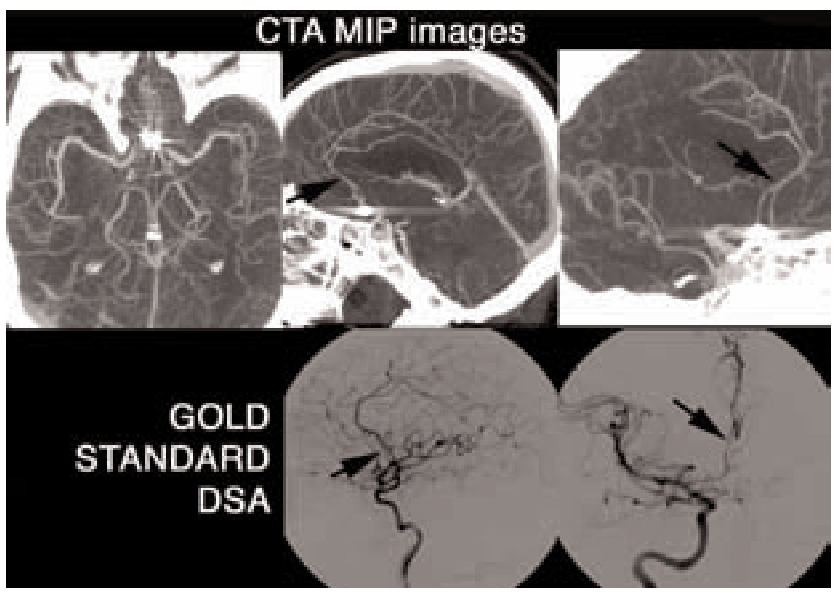


FIGURE 4. Patient transferred at day 8 to our neurovascular ICU from outside institution after coiling of ruptured anterior communicating artery aneurysm. Noncontrast CT obtained at admission of patient in ICU demonstrates extensive residual subarachnoid hemorrhage and suspicious loss of gray-white matter contrast in left superior frontal gyrus (white arrows). Tip of right ventricular drain catheter is also visible. On perfusion CT (PCT), significantly abnormal brain perfusion in distribution of anterior and inferior branches of left (also, to a lesser extent, right) anterior cerebral arteries (ACA, arrowheads) and of right posterior middle cerebral artery (MCA) branches is seen primarily on MTT and TTP (time to peak) maps. The rCBF was also slightly decreased in the same territories, whereas rCBV was mainly preserved (it is lowered only in left superior frontal gyrus, star). CT angiography confirmed suspicion of moderate vasospasm of both A2 and A3 segments of ACA (arrows), ultimately verified by gold standard DSA. No abnormality of right posterior MCA branches was identified. Artifacts created by coils on CTA images obscure A1 segments bilaterally and interfere with their evaluation. Endovascular therapy (IA verapamil) was performed in ACA territories during DSA.

CTA/perfusion CT with DSA. Although CTA results alone lacked sensitivity per presence/absence of vasospasm, they were very specific (96.3%). The study also found, however, that the perfusion CT value of mean transit time (MTT) showed excellent sensitivity (95.1%). The study thus suggested that using a combination of a sensitive MTT threshold for vasospasm screening with CTA as a specific confirmatory test could serve as an accurate noninvasive predictor of angiographic vasospasm (Figure 4).

CONCLUSION

Modern multislice CTA is a sensitive technique to screen for intracranial aneurysms, and it is able to provide complete aneurysm characterization. Image acquisition and processing can be performed rapidly on commercially available devices. CTA image information has been shown to assist in treatment selection and planning. ■

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