AJNR

Multi-Detector Row CT Angiography with Direct Intra-Arterial Contrast Injection for the Evaluation of Neurovascular Disease: Technique, Applications, and Initial Experience

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TECHNICAL NOTE

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SUMMARY: The purpose of this study was to evaluate the usefulness of 64-section multi-detector row CT angiography (CTA) with direct intra-arterial contrast injection (IA-CTA) for the evaluation of neurovascular disease. This technique was used in 11 patients at our institution. All studies were technically successful, and there were no complications. Small vascular malformations were mapped easily on high-resolution IA-CTA images, enabling microsurgical resection or stereotactic radiosurgery. In a similar fashion, additional morphologic features were revealed on IA-CTA images not seen on standard 2D and 3D digital subtraction angiography. Of 11 patients undergoing IA-CTA, 7 patients had further anatomic clarity of the small arteriovenous fistula/malformation and 4 patients had changes in the treatment plan on the basis of the IA-CTA findings.

CT angiography (CTA) is a noninvasive imaging technique that can produce accurate, high-resolution angiographic projections of the cerebral vasculature after intravenous injection of radiographic contrast media. Widely used in the setting of subarachnoid hemorrhage (SAH), CTA has even replaced digital subtraction angiography (DSA) at certain institutions as a primary diagnostic tool for evaluation of patients with SAH.[1,2] Some of the relative weaknesses of CTA include difficulty in evaluating lesions arising from small (especially cortical or perforating) vessels, lack of dynamic information, limited sensitivity for small aneurysms, and frequent interference in interpretation by adjacent cortical bone and calcification.[3,4]

Small but important vessels such as the meningohypophyseal trunk, lenticulostriate arteries, and recurrent artery of Heubner are not consistently visualized on standard intravenous (IV) CTA.[5] This is most likely because of poor bolus characteristics of contrast medium diluted in the heart. Thus, IV-CTA is not favored for the evaluation and/or localization of vascular pathologic lesions such as dural or pial fistulas, small arteriovenous malformations (AVMs), and small aneurysms. To improve visualization and to facilitate therapy of such small vascular pathologic lesions, we have begun to perform CTA with intra-arterial injection of contrast. This prevents the dilution factor associated with IV-CTA, thus providing better bolus characteristics and, in turn, higher-quality imaging.[6] Intra-arterial CTA (IA-CTA) has previously been described by Nojiri et al[7] in describing the morphologic features of the artery of Adamkiewitz. Understanding the challenges of imaging small vascular lesions, we describe our technique of performing IA-CTA for the delineation of small cerebrovascular pathologic conditions as well as for treatment planning.

Technique

This study represents a retrospective analysis of 11 patients undergoing IA-CTA at our institution in an 18-month period (April 2006 to October 2007). The University of Michigan Institutional Review Board approved our study, and informed consent was obtained from each patient or their next of kin before the procedure was initiated. The consent process included informing the patients and/or their families about the novel nature of this technique and detailed discussion of possible risks, benefits, and uncertainties.

Access and Diagnostic Catheter Placement

Ten of the 11 patients received local anesthetic and remained awake during the procedure, whereas 1 pediatric patient required general anesthesia. Transfemoral access was obtained with the standard Seldinger technique with placement of a 4F or 5F femoral sheath. Patients were then given an intravenous bolus of 2000 to 4000 U of heparin. Next, the diagnostic catheter (4F or 5F) of choice was connected to a continuous heparinized flush and guided within the vessel of interest with a 0.035-inch glidewire. At this time, a biplane DSA was obtained (Axiom Artis; Siemens, Erlangen, Germany).

Patient Transport

Nine patients were physically transported to the CT scanner, whereas 2 patients were studied in a recently installed hybrid CT DSA suite (Siemens). Patients requiring transport were placed in a cervical collar to minimize neck movement during transportation. In addition, catheter position was secured with towel clips and adhesive dressing, and sterility was maintained by placement of a sterile drape over the patient and the catheter.

CT Angiography with Intra-Arterial Injection

CTA studies in 9 patients were obtained on multidetector 64-section CT (Lightspeed VCT; GE Healthcare, Milwaukee, Wis, or Somatom and Angio Miyabi; Siemens). The scan parameters included 0.625-mm section thickness, 0.4-s gantry rotation time, 120 kV, 650 to 800 mA, and scan times varying from 3.2 to 4 s. Omnipaque 300 (300 mg I/mL, GE Healthcare) was diluted to 50% with normal saline. Injection rates varied from 0.5 to 4 mL/s depending on the vessel of
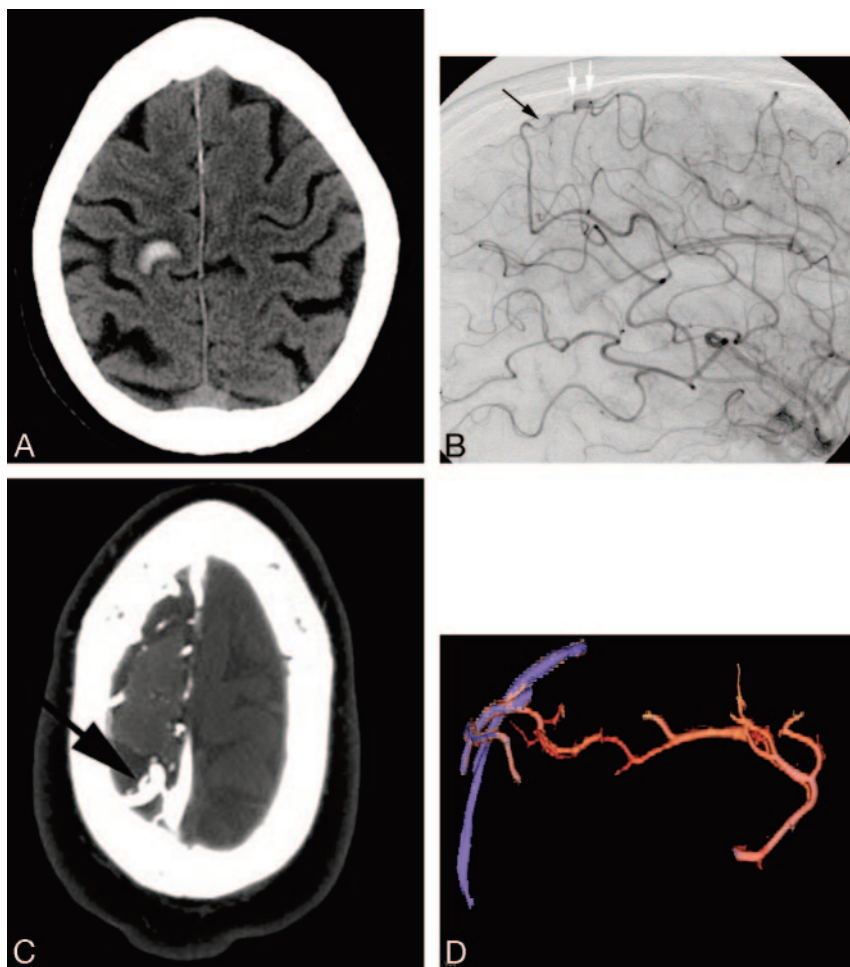
Fig 1. Patient 7. This patient presented with acute onset of left leg numbness. *A*, A noncontrast CT scan demonstrates a small bleed in the right parietal lobe. *B*, An oblique, magnified image of cerebral DSA reveals a tiny pial AVF (*black arrow*) drained by an early filling cortical vein (*white arrows*). Given the fairly superficial location of the lesion and recent history of bleed, surgical resection was recommended. *C*, A source image of IA-CTA reveals the point of connection between the parietal branch of the right anterior cerebral artery (*arrow*) and adjacent cortical vein. *D*, 3D volume-rendered images reveal the feeding artery, fistula, and the draining vein (labeled *blue*). The knowledge of the cross-sectional anatomy helped significantly when planning surgical approach. This lesion could be easily found, confirmed at surgery, and clipped.

interest (1 mL/s for the external carotid artery, 2 mL/s for the internal carotid artery [ICA] and vertebral artery, 3 mL/s for the common carotid artery, 4 mL/s for the subclavian artery, and 0.5 mL/s for the middle meningeal artery). Injection was begun 2 s before CTA acquisition was initiated, and the imaging data were transported to either Vitrea (Vital Images, Minnetonka, Minn) or Advantage Windows 4.2 (GE Healthcare) workstations. Multiplanar 2D and 3D reformats were performed, and the data were reviewed by 2 experienced interventional neuroradiologists and a dedicated neurovascular surgeon.

Results

IA-CTA Studies

All 11 patients underwent the procedure successfully without any complications. The quality of all IA-CTA studies was rated as excellent by all reviewers as a very high-attenuation of intravascular contrast was observed because of direct intra-arterial injections. Attenuation values in excess of 1200 U were obtained in the main branches (anterior cerebral artery and middle cerebral artery) of the circle of Willis. It was possible to demonstrate many small arteries (mandibular artery, meningohypophyseal trunk, and distal branches of the lenticulostriate arteries) by using this technique; these arteries are usually

not visualized on IV-CTA and MR angiography (MRA) techniques.

Patient Findings

All patients in this series had undergone previous clinical and imaging evaluations: CT ($n = 10$), IV-CTA ($n = 3$), MR imaging ($n = 7$), MRA ($n = 1$), and DSA ($n = 11$). On the basis of these initial evaluations, the diagnoses were as follows: intracranial dural arteriovenus fistula [AVF] ($n = 3$), spinal dural AVF ($n = 2$), cerebral pial fistulas ($n = 3$; Fig 1), tectal microarteriovenous fistula ($n = 1$), and intracranial aneurysm ($n = 2$; Fig 2; on-line table). All shunting lesions (AVF/AVM) measured less than 1.4 cm in their maximal diameter, and 6 patients had subcentimeter lesions (patients 1, 3, 5, and 6–8). In 3 patients (patients 6, 7, and 9), a direct comparison of IA-CTA was available with previously performed IV-CTA. In all 3 patients, the IA-CTA added significant additional information helpful for the treatment decisions.

In 7 patients, a definite diagnosis of a small shunting lesion was made on initial work-up. However, treating physicians (neurovascular surgeon or radiation oncologist) preferred that the fistula be mapped on cross-sectional study before sur-
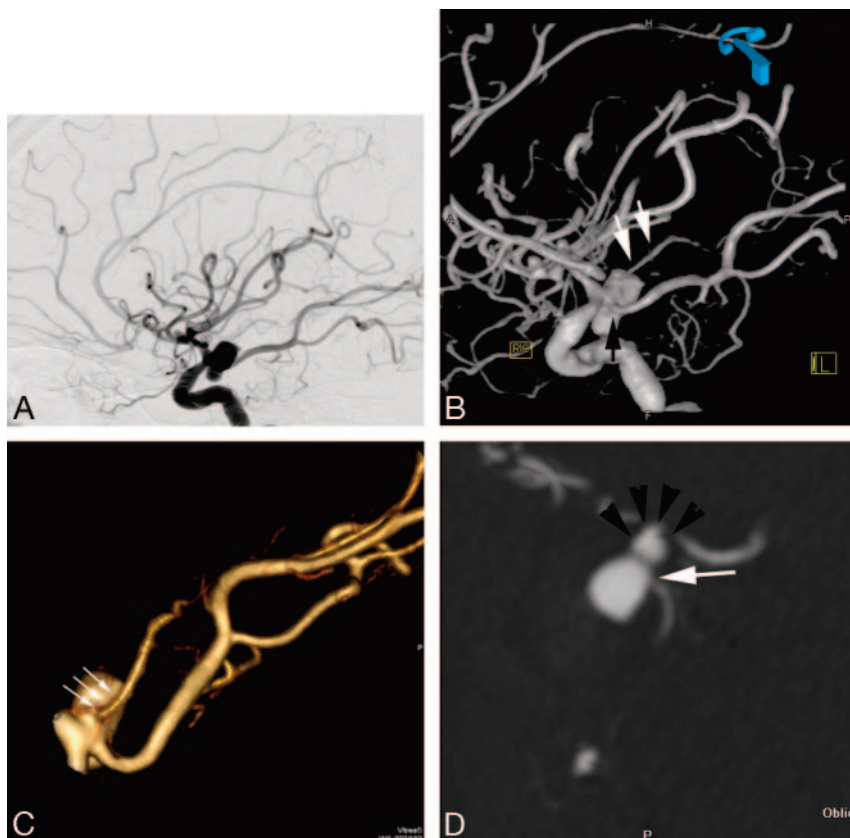
Fig 2. Patient 10. This patient is a 50-year-old-woman who presented at our emergency department with diffuse SAH. *A*, Lateral view of the LICA demonstrates a multilobulated, complex aneurysm. *B*, 3D DSA reveals that the posterior communicating artery is originating from the aneurysmal neck (*black arrowhead*). Even on 3D imaging, the origin of the anterior choroidal artery (*white arrows*) cannot be located in relationship to the aneurysmal neck. *C*, A 3D IA-CTA clearly reveals that the anterior choroidal artery (*white arrows*) arises from the proximal aneurysmal dome. *D*, Magnified axial source image reveals the supraclinoid internal carotid artery anteriorly (*black arrowheads*). The anterior choroidal artery origin from the dome of the aneurysm is again easily identified. This excluded endovascular management, and this aneurysm was surgically clipped.

gical resection or stereotactic radiosurgery (patients 1–3, 5, and 6–8). IA-CTA could map these fistulas with accuracy and facilitate definitive treatment in these patients harboring small vascular lesions (on-line Table).

In 1 patient (patient 9), with a history of SAH, a shunt surgery lesion in the tectal region was suspected on DSA. However, even on high-frame DSA (15 frames/s), it was difficult to be certain whether this lesion was an AVM or a fistula. IA-CTA in this patient helped make a definitive diagnosis of a micro-AVM of the tectal region and thus facilitated stereotactic radiosurgery (Fig 3). In another patient with a history of SAH and previously embolized posterior communicating artery aneurysm, an incidental pial AVF was suspected on DSA. IA-CTA was performed with intent to map the fistula, but this study failed to identify the lesion. Further review of the DSA studies demonstrated a focal region of dilation of the superficial temporal artery that had overlapped with a frontal branch of MCA, thus simulating a pial AVF.

There were 2 patients with intracranial aneurysms in this study (patients 10 and 11). One patient (patient 10) had experienced a diffuse SAH from a ruptured right posterior communicating aneurysm. A cerebral DSA demonstrated complex, multilobulated aneurysm with the posterior communicating artery arising from its neck. However, we could not reliably identify the origin of the anterior choroidal artery on either the 2D or 3D DSA. We suspected that the failure of 3D DSA to demonstrate the origin of the anterior choroidal

artery was on account of transient and "flash" filling of this artery rather than its continuous opacification during the acquisition of rotational information. An IA-CTA in this patient was very helpful because it demonstrated the anterior choroidal artery arising from the proximal neck of the aneurysm. This precluded endovascular therapy, thus necessitating microsurgical clipping (Fig 2). Another patient (patient 11) had a 13-mm aneurysm in the carotid siphon. Despite high-frame rate 2D and 3D DSA, we could not be certain of the origin of the aneurysm (cavernous vs paraclinoid). IA-CTA was superior to DSA to define the neck of this aneurysm and confirmed the cavernous origin of the aneurysm. In summary, 7 patients had further anatomic clarity of the small vascular lesions, whereas the other 4 patients had changes in the treatment plan on the basis of the IA-CTA findings.

Discussion

Recent advances in neuroimaging techniques (high-resolution CTA and MRA) have resulted in improved understanding and treatment of neurovascular disorders. Time resolved (dynamic) MRA and dynamic CTA techniques have become available that provide noninvasive assessment of blood flow and cerebral hemodynamics.[8,9] Nonetheless, the spatial resolution of dynamic CTA and MRA techniques remains inferior to conventional angiography. DSA remains the reference standard for the evaluation of small vascular lesions but lacks the capability of providing information regarding surrounding
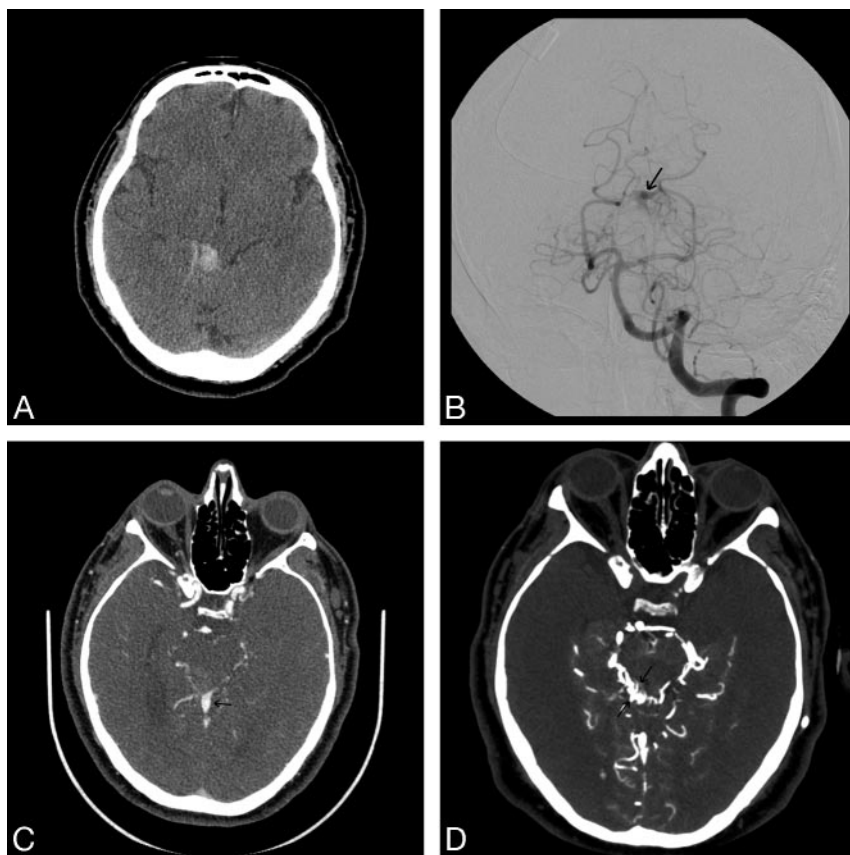
Fig 3. Patient 9. This patient is a 56-year-old man who presented with acute-onset headache and sudden neurologic deficits. *A*, Noncontrast CT scan demonstrates a focal hematoma in the midbrain. *B*, A high-frame rate DSA image of a left vertebral angiogram reveals small branches of the superior cerebellar artery in the region of the midbrain with an adjacent, early filling superior vermian vein (*arrow*). However, it could not be inferred with certainty whether this lesion is a fistula or a true AVM. *C*, A source image of IV-CTA reveals an abnormal, early filling superior vermian vein (*arrow*), but the nidus of the AVM is very difficult to identify. *D*, Source image of IA-CTA clearly demonstrates the nidus of a micro-AVM (*arrows*) in the region of the midbrain tectum as well as multiple tiny arterial feeders. The IA-CTA was considered superior to DSA as well as to IV-CTA in mapping as well as characterization of this tiny AVM. Wider window settings are intentionally used to demonstrate the individual tiny branches supplying this lesion.

cerebral parenchyma. We propose the usefulness of IA-CTA not only to provide better visualization of small vascular lesions but also cerebral parenchymal imaging to guide surgical or radiosurgical planning.

Microsurgical resection and stereotactic radiosurgery remain the 2 main venues as curative procedures for AVMs and AVFs. In our series, 3 patients with shunting lesions underwent IA-CTA as preoperative planning for surgical resection. The neurovascular surgeon found it extremely helpful to localize and visualize the fistula on CT and, in turn, planning and making surgical resection more feasible.

Stereotactic radiosurgery is also an attractive option for the treatment of pial vascular malformations and dural AVFs.[10-12] The target delineation for stereotactic radiosurgery of AVMs and AVFs is commonly performed by DSA and is coregistered with stereotactic CT or MR imaging scans.[13] Observer variation, imaging factors, and AVM-related factors can result in ambiguity when the nidus for purposes of radiosurgery is being determined.[14] The main limitation of DSA is that it presents only 2D information on the nidus, but radiosurgical treatment planning requires accurate 3D targets. Our IA-CTA method allows detailed evaluation of the AVM nidus or location of a fistulous connection, thus circumventing the need for image fusion with DSA.

We have limited experience with IA-CTA in the evaluation

of aneurysms, but in both of our patients with aneurysms, IA-CTA helped with clinical decision making. In 1 patient, it demonstrated that the anterior choroidal artery arose from the proximal neck of the aneurysm, which was difficult to appreciate even with 3D DSA. In another patient, it was difficult to determine whether the aneurysmal neck was arising from the cavernous segment or the supraclinoid segment of the ICA. IA-CTA clearly showed the neck to be in the cavernous carotid. IA-CTA will become more feasible to perform with the arrival of a hybrid CT-DSA suites; thus preventing patient transportation with IA catheters. Such hybrid systems could allow for IA-CTA to be performed in conjunction with routine cerebral angiography.

Although IA-CTA offers tremendous anatomic clarity, it certainly is a more invasive method of imaging; thus, the risks for vessel dissection, spasm, and catheter displacement could become a source of cerebrovascular accident. Although we did not encounter any complications, such risks could be inherent to this procedure. In addition, IA-CTA lacks spatial and temporal resolution compared with DSA. We can only study single vessels at a time with IA-CTA compared with IV-CTA, which allows for multiple vessels to be analyzed during 1 evaluation. As IA-CTA involves both a DSA and a CTA, patients are exposed to higher dosages of radiation. IA-CTA is a more invasive and expensive diagnostic tool and thus would likely

not be used for larger lesions that are easily visualized on current CT or MR imaging technology. Nonetheless, IA-CTA does provide an exceptional level of detail, which could prove essential in the understanding and surgical planning of some complex and small vascular pathologic lesions.

Conclusions

In our series, IA-CTA seems to be a safe method for localization and characterization of subtle neurovascular lesions. Preoperative imaging with this method can aid in surgical planning (embolization, microsurgery, or radiosurgery) for small AVFs and complex aneurysms. This study represents a small retrospective analysis; thus, no conclusions can be drawn without further evaluation of IA-CTA in a larger population. Nonetheless, with the arrival of hybrid CTA suites, IA-CTA could become a routine part of cerebral angiography when deemed necessary.

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