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Benefit of cone-beam computed tomography angiography in acute management of angiographically undetectable ruptured arteriovenous malformations

Clinical article

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Object. Ruptured arteriovenous malformations (AVMs) are a frequent cause of intracerebral hemorrhage (ICH). In some cases, compression from the associated hematoma in the acute setting can partially or completely occlude an AVM, making it invisible on conventional angiography techniques. The authors report on the successful use of cone-beam CT angiography (CBCT-A) to precisely identify the underlying angioarchitecture of ruptured AVMs that are not visible on conventional angiography.

Methods. Three patients presented with ICH for which they underwent examination with CBCT-A in addition to digital subtraction angiography and other imaging modalities, including MR angiography and CT angiography. All patients underwent surgical evacuation due to mass effect from the hematoma. Clinical history, imaging studies, and surgical records were reviewed. Hematoma volumes were calculated.

Results. In all 3 cases, CBCT-A demonstrated detailed anatomy of an AVM where no lesion or just a suggestion of a draining vein had been seen with other imaging modalities. Magnetic resonance imaging demonstrated enhancement in 1 patient; CT angiography demonstrated a draining vein in 1 patient; 2D digital subtraction angiography and 3D rotational angiography demonstrated a suggestion of a draining vein in 2 cases and no finding in the third. In the 2 patients in whom CBCT-A was performed prior to surgery, the demonstrated AVM was successfully resected without evidence of a residual lesion. In the third patient, CBCT-A allowed precise targeting of the AVM nidus using Gamma Knife radiosurgery.

Conclusions. Cone-beam CT angiography should be considered in the evaluation and subsequent treatment of ICH due to ruptured AVMs. In cases in which the associated hematoma compresses the AVM nidus, CBCT-A can have higher sensitivity and anatomical accuracy than traditional angiographic modalities, including digital subtraction angiography.

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Key Words • **arteriovenous malformation** • **cone-beam computed tomography** • **vascular disorders** • **imaging**

Patients presenting with ICH must be accurately and expeditiously diagnosed and treated to limit morbidity and mortality.[10] A significant portion of these patients, especially younger patients without a history of hypertension, can harbor an underlying lesion, and up to 25% have a cerebral AVM.[18] In the pediatric population, AVM may cause up to 50% of cases of ICH.[9] Knowledge of the vascular anatomy of an underlying AVM is necessary to determine the appropriate follow-up and treatment, be that resection or radiosurgery. In cases requiring urgent surgical decompression, diagnosis of an underlying AVM can provide information that is crucial for avoiding significant morbidity during surgery, as interruption of venous drainage can lead to devastating hemorrhage or cerebral edema.[2,7,16]

One of the challenges of treating a ruptured AVM is the fact that the nidus can be compressed by the acute hematoma, thereby rendering it undetectable on noninvasive imaging or DSA. Although this is usually dealt with by allowing the clot to partially resorb and performing delayed or repeat angiography, such an expectant approach may not be feasible in the setting of symptomatic or life-threatening hematoma. For example, mass effect from the acute hemorrhage or rapidly worsening edema in the subacute setting may require urgent decompression, while

Abbreviations used in this paper: AP = anteroposterior; AVM = arteriovenous malformation; CBCT-A = cone-beam CT angiography; CTA = computed tomography angiography; DSA = digital subtraction angiography; ICA = internal carotid artery; ICH = intracerebral hemorrhage; MIP = maximum intensity projection; MPR = multiplanar reconstruction: MRA = MR angiography.

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the AVM may still remain angiographically undetectable by conventional angiography. Even when performed in a delayed fashion, angiography may not be 100% sensitive.

Cone-beam CT utilizes the flat-panel capability of current digital angiography systems to perform high-density acquisition and reconstruction. Initially used to enable emergent imaging to detect intraprocedural hemorrhage in neuroendovascular procedures, it has been shown to provide high spatial and contrast resolution. Cone-beam CT angiography (CBCT-A), performed with contrast injection, has been used to detect intraluminal thrombus and plaque morphology and define vascular architecture.[1,3,8] We report on the use of this technique in the setting of ICH and its effect on the management of acutely ruptured AVMs.

Methods

Case Selection

Angiographic workup of intracerebral hemorrhage during initial presentation is undertaken at our institution in patients who do not fit criteria for hypertensive hemorrhage or amyloid angiopathy (that is, younger patients and/or patients without hypertension or other risk factors). In select patients, diagnostic cerebral angiography is performed in addition to noninvasive imaging modalities when the clinical suspicion remains high despite negative results on noninvasive imaging. Since 2009, we have encountered 3 patients with intracerebral hemorrhage in whom no clear etiology had been found, in whom CBCT-A demonstrated an AVM at the periphery of the hematoma. Charts and imaging studies were reviewed for clinical and radiographic information.

Procedures

Informed consent was obtained after discussion of procedure risks and benefits with the patient or the patient's proxy when appropriate. All procedures were performed in the Axiom Artis biplane neuroangiogaphy suite (Siemens AG). After conventional biplane and 3D rotational angiography (performed using 3 ml/sec of contrast medium for 5 seconds with a 1.5-second preinjection delay), CBCT-A was performed using 20-second acquisition while injecting contrast medium at 1 ml/second with a 2.0-second preinjection delay (Isovue-250, Bracco Imaging SpA).

Analysis

The CBCT-A volumes were reconstructed using MIP MPR on a Leonardo/Syngo workstation (Siemens AG) and the Osirix medical imaging software (Osirix Foundation). Hematoma volume was calculated by means of volumetric region of interest calculations using Osirix.

Ethical Considerations

Informed consent was obtained from patients or their appropriate decision maker prior to all procedures. Chart reviews were conducted under the approval of the Tufts Medical Center institutional review board.

Results

Demographic characteristics, presenting symptoms, location and size of hematoma, as well as available imaging modalities and findings are displayed in Table 1. The mean hematoma size was 42.3 ± 9.4 cm^3 (SD). Two patients underwent craniotomy and hematoma evacuation after the AVM was discovered and one patient underwent emergent evacuation with subsequent Gamma Knife radiosurgery to an AVM that was discovered only after hematoma resection. Hematoma evacuation was successful in all 3 cases, with stabilization or improvement of neurological status and decreased mass effect and edema on postoperative CT. In the 2 cases in which the AVM location was known prior to surgery, the AVM was found in the predicted location and resected successfully. In the third case, Gamma Knife radiosurgery was targeted to the AVM nidus visualized only by CBCT-A. Details of the first case are discussed below, with imaging findings displayed in Fig. 1. Figures 2 and 3 depict imaging findings in cases 2 and 3.

Case Illustration

This 5-year-old girl with an unremarkable medical history was transferred from a community hospital with a large temporal ICH after presenting with progressive

TABLE 1: Presentation, imaging, and intervention in 3 cases*

Case No.	Age (yrs), Sex	Presentation	Location	Hematoma Vol (cm^3)	CTA	MRI	MRA	2D DSA	3D DSA	Intervention
1	5, F	headache, altered mental status, somnolence	left temporal	34.4	NA	enhancement along border of hematoma	ND	ND	ND	immediate hematoma evacuation & resection of AVM
2	57, M	right hemiparesis, aphasia	left temporal	52.7	ND	NA	NA	DV	NA	hematoma evacuation prior to knowledge of AVM; subsequent GKS
3	31, M	headache, aphasia, right hemiplegia	left frontoparietal	39.9	DV	NA	NA	DV	DV	emergent hematoma evacuation & resection of AVM 1 wk after presentation

* DV = possible draining vein; GKS = Gamma Knife radiosurgery; NA = not available; ND = not detected.

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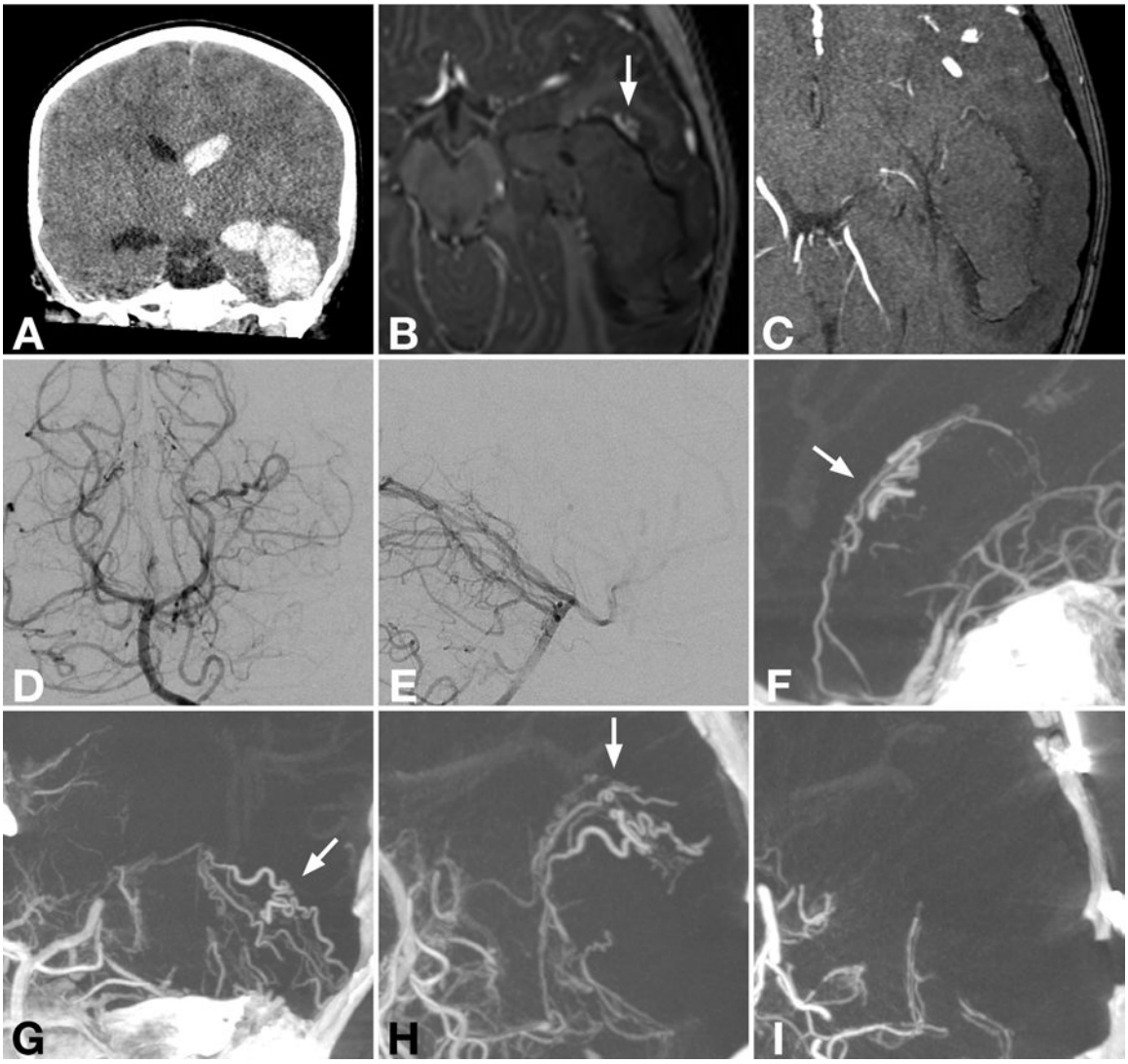


Fig. 1. Case 1. Preoperative (A–H) and postoperative (I) images obtained in a 5-year-old girl who presented with progressive headache, vomiting, and confusion. **A:** Noncontrast coronal CT reconstruction. **B:** Axial T1-weighted Gd-enhanced MR image. **C:** Axial MR angiogram. **D and E:** Left vertebral artery injection AP (D) and lateral (E) view DSA. **F–H:** Sagittal (F), coronal (G), and axial (H) MIP-MPR CBCT-A. **I:** Axial MIP-MPR CBCT angiogram obtained 4 days after surgery.

headache, vomiting, and confusion. Computed tomography demonstrated left posterior temporal ICH with a volume of 34.4 cm^3, intraventricular hemorrhage casting the left lateral ventricle and third ventricle, and hydrocephalus (Fig. 1A). A right frontal ventriculostomy drain was placed emergently. Magnetic resonance imaging demonstrated a region of abnormal enhancement in areas surrounding the hemorrhage, but no abnormal vasculature was evident on MRA (Fig. 1B and C). Left vertebral artery 2D-DSA demonstrated an enlarged left posterior temporal artery suggesting a possible feeder to an AVM, but no nidus or draining veins were visible (Fig. 1D and E). CBCT-A of the left vertebral artery, however, demonstrated a clearly defined AVM at the anterior-superior pole of the hematoma, fed by the posterior temporal branch of the left posterior cerebral artery (Fig. 1F–H, arrows).

The patient successfully underwent a left temporal craniotomy for hematoma evacuation and resection of the AVM. The AVM was found and resected at the anterior-superior margin of the hematoma cavity, as seen on the CBCT imaging. Postoperative angiography and CBCT-A demonstrated no evidence of a residual lesion (Fig. 1I). At the 6-month follow-up visit, the patient was neurologically intact, seizure free, and doing well.

Discussion

Angiographic Imaging in Patients with ICH

The American Heart Association and American Stroke Association maintain guidelines for the diagnosis and management of spontaneous ICH, but the role of various imaging modalities for the diagnosis of a secondary cause of hemorrhage remains incompletely defined.[10] The most recent recommendations assign a Class IIa, level of evidence B to further evaluation of ICH patients with a high degree of suspicion for an underlying structural lesion,

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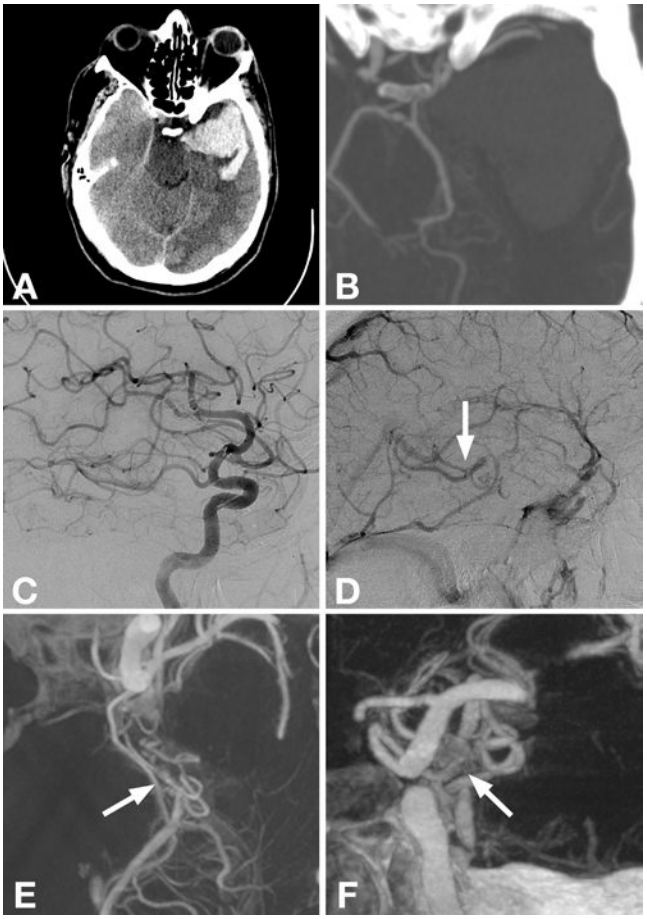


Fig. 2. Case 2. Images obtained in a 57-year-old man presenting with unresponsiveness and dense right hemiplegia. **A:** Noncontrast CT scan demonstrating left temporal ICH with uncal herniation. **B:** Axial CT angiogram demonstrating no evidence of vascular malformation. **C:** Left ICA injection arterial-phase lateral DS angiogram failing to reveal an AVM nidus. **D:** Venous phase lateral angiogram showing an early draining vein near the mesial left temporal lobe *(arrow)*. **E and F:** Axial (E) and coronal (F) CBCT-A multiplanar MIP reconstructions demonstrating an AVM nidus *(arrows)* on left ICA injection.

but give no recommendations as to the imaging modality of choice. Diagnostic cerebral angiography was found by Zhu et al.[18] to provide a significantly higher sensitivity in patients under the age of 45 years or older without a history of hypertension or hemorrhage in thalamus, putamen, or posterior fossa. The authors did not compare findings of CTA or MRA in their series, however.

To date, there have been several small studies comparing imaging modalities for the detection of cerebral AVM.[5,6,12,13,17] However, CT, MR, and DSA technologies continue to advance, and comparisons from just a few years ago may not remain valid with more recent technology. Recently, using time-of-flight MRA, Wong and colleagues[17] demonstrated a positive predictive value of 0.98 for finding an AVM or dural arteriovenous fistula. Gross and colleagues[6] studied 125 patients with AVM and demonstrated 90% sensitivity for CTA, 89% for T2-weighted MRI, and 74% for MRA, although in cases of acute rupture the sensitivity dropped to only 88%, 29%, and 27%, respectively. Fasulakis and Andronikou[5] studied MRA and DSA in children and found that in a group of 19 patients with known AVM, aneurysm, or subarachnoid hemorrhage, MRA was equally sensitive for AVM. In 2 of their cases, MRA provided additional information not seen on DSA.

In our pediatric patient, neither MRA nor DSA demonstrated a lesion, though a possible abnormality was detected on contrast-enhanced T1-weighted images (Fig. 1B). Both adult patients were initially evaluated with CTA. In Case 2, CTA showed no evidence of AVM, and in Case 3, it showed a single draining vein suspicious for an underlying lesion, without evidence of an AVM nidus. In all 3 cases, the findings on CTA or MRA matched the findings on 2D DSA and 3D rotational angiography. Not until the patients underwent CBCT-A were the AVMs and their niduses fully visualized. We propose that acute compression of the small vessels within the AVM nidus made them so small as to be nearly invisible on traditional imaging methods. Only after CBCT-A highlighted these small arteries was the nidus able to be visualized.

Cone-Beam CT Angiography

Cone-beam CT has been shown to be a valuable imaging modality during catheter-based angiography. With respect to neuroendovascular techniques, its first application was rapid assessment of postprocedure hemorrhage during coil embolization of cerebral aneurysms.[3] CBCT-A offers excellent spatial resolution, while sacrificing time resolution.[14] These properties have led to several applications including stereotactic localization of vascular lesions.[15]

Cone-beam CT also provides a degree of soft-tissue and bony anatomical information not available with DSA, which can aid the surgeon in localizing the lesion at the time of surgery using bony and soft-tissue landmarks. In addition, CBCT can be colocalized with existing stereotactic navigation systems to provide precise localization of the nidus during resection. The AVM in Case 3 was easily located within the hematoma cavity using this technique and intraoperative frameless stereotactic navigation. The AVM in Case 2 was treated using Gamma Knife radiosurgery, localized with the CBCT-A data with the Leksell frame in place.

On the other hand, CBCT-A acquisition requires 20 seconds and its use requires a cooperative patient or one who is sedated to enable imaging without undue head movement. As in other cross-sectional imaging modalities, such as conventional CT or MRI, head movement will result in deterioration. We routinely use CBCT to examine patients who are able to hold still and are able to follow breath-holding instructions. In some cases where there is clinical need, the patient may need to be electively intubated if intubation has not already been performed because of the underlying presentation. It is certainly not possible to compensate for some gross head movement as is possible by means of pixel shifting in 2D DSA.

With regard to safety, a single 20-second CBCT-A acquisition is associated with 212 mGy radiation exposure and involves the injection of 22 ml of contrast, compared with 64.8 mGy for a subtracted 3D rotational angiography with injection of 18 ml of contrast, and 130–160 mGy for a

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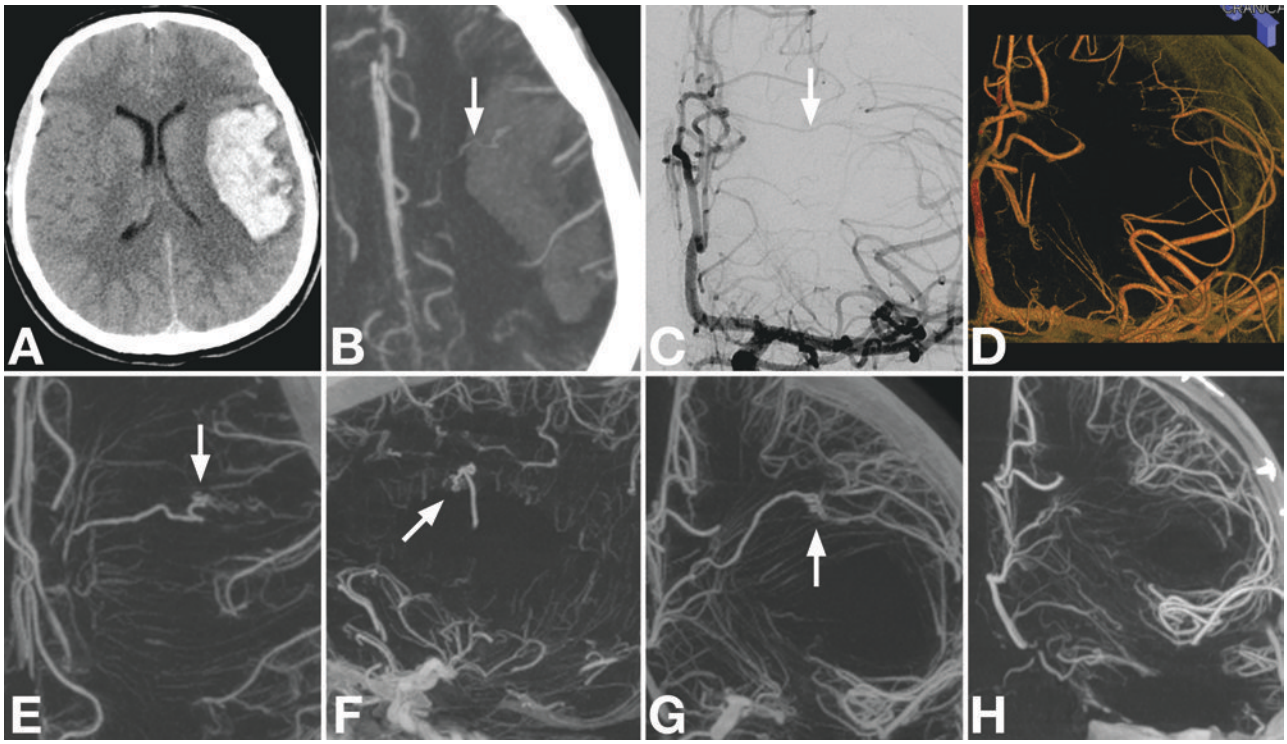


Fig. 3. Case 3. Images obtained in a 31-year-old man presenting with sudden headache, aphasia, and right arm weakness. **A:** Noncontrast CT demonstrating left frontoparietal ICH. **B:** Axial MIP-MPR CT angiogram showing a possible abnormal draining vein *(arrow)*. **C and D:** Left ICA injection AP DS angiogram (C) and 3D rotational angiogram (D) demonstrating the vein seen on CTA *(arrow)* but no AVM nidus. **E–G:** Axial (E), sagittal (F), and coronal (G) CBCT angiograms demonstrating a compressed AVM fed by branches of the middle cerebral artery *(arrows)*. **H:** Postoperative coronal CBCT angiogram demonstrating resection of the AVM without evidence of a residual lesion.

biplane carotid DSA run with injection of 8 ml of contrast. Our current angiography protocol entails a biplane angiogram followed by 3D rotational angiography and then additional high-magnification 2D DSA as warranted for optimal projection of a lesion or region of interest. In cases of hemorrhage of unclear etiology, 3D rotational angiography is followed by CBCT-A. The total additional radiation dose is not increased significantly compared with the possible need for multiple magnified 2D DSA projections of the area of hemorrhage. Ultimately, the decision to pursue CBCT-A should be made on a case-by-case basis by the clinical neurosurgical team based on the patient's presentation and a priori likelihood of an underlying lesion.

Detection of Vascular Pathology in the Setting of Hemorrhage

The 3 cases of ICH presented in this series were caused by AVMs that were not visible on CTA, MRI, MRA, DSA, or 3D rotational angiography, but were clearly seen using CBCT-A. Digital subtraction angiography has remained the gold standard for diagnosis of AVM in the setting of ICH, but these cases suggest that even DSA lacks 100% sensitivity.

CBCT-A may have higher sensitivity than DSA in these cases for a few reasons. First, because of the longer period of acquisition in CBCT-A, the contrast agent may be able to reach the nidus of an AVM at the lower flow rate induced by compression from a hematoma. Additionally, the higher gain and sensitivity afforded by CBCT-A enables clear detection of this minimal contrast enhancement. Merely extending the duration of the acquisition of other modalities may not be sufficient given their lower sensitivity, and using a shorter acquisition duration with a higher rate of injection may not allow for sufficient time for the contrast agent to reach and opacify the nidus clearly, given the lower flow rate of the compressed AVM. We are, like many other groups, still learning the utility of this new imaging protocol, which is part of modern angiography equipment, and these properties may have use in other slow-flow or microvascular lesions.

Underlying vascular pathology may be present in a high percentage of "angiographically negative" cases of ICH, especially in patient populations with a high a priori suspicion for an underlying cause of hemorrhage. Elhammady et al.[4] prospectively studied 9 younger patients undergoing craniotomy for cryptogenic ICH. In 7 of 9 cases they found an underlying histopathological cause for the hemorrhage, including 3 angiographically negative AVMs, 3 cavernous malformations, and 1 neoplasm. Young, healthy patients with cryptogenic hemorrhage were shown to have excellent outcome after exploratory craniotomy in this series. We feel that in these situations CBCT-A may elucidate a portion of these formerly cryptogenic lesions, allowing the surgeon to more safely plan the surgical approach and accurately resect the lesion.

Despite this, it must be remembered that CBCT-A

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may not be 100% sensitive. Mutoh et al.[11] have presented a case of a 48-year-old woman with subarachnoid hemorrhage who was found to have a vascular malformation despite negative angiographic workup including CBCT. It may be that CBCT did not detect a lesion in this case because contrast medium was not injected during acquisition, but it cannot be ruled out that some vascular lesions remain angiographically occult despite the resolving detail of CBCT.

Conclusions

In some cases in which other contemporaneous modalities fail to detect a vascular lesion, CBCT-A can provide high-sensitivity detection of acutely ruptured and compressed AVMs, with excellent spatial and contrast resolution of angioarchitecture. CBCT-A may provide higher sensitivity than traditional angiographic modalities in these cases due to compression of the AVM by hematoma. We suggest that CBCT-A may be helpful in the evaluation of ICH when an underlying lesion is suspected. Further investigation into the uses of this technology and indications for its use are warranted.

Disclosure

The senior author (A. M. Malek) has received unrestricted research funding from Codman Neurovascular, Stryker Neurovascular, Microvention-Terumo Inc., Siemens Medical Imaging, Ansys Inc., and CD-Adapco for research that is unrelated to this work. Dr. Rahal has no conflict of interest to declare with respect to the study.

Author contributions to the study and manuscript preparation include the following. Conception and design: Malek. Acquisition of data: both authors. Analysis and interpretation of data: both authors. Drafting the article: Rahal. Critically revising the article: both authors. Reviewed submitted version of manuscript: both authors. Approved the final version of the manuscript on behalf of both authors: Malek. Administrative/technical/material support: Malek. Study supervision: Malek.

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