

Original Article

Dual-energy CT angiography for the diagnosis of intracranial dural arteriovenous fistula

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Abstract: Purpose: To investigate the clinical utility of dual-source dual-energy CT angiography (DSDECTA) for diagnosing intracranial dural arteriovenous fistula (DAVF). Methods: Nine intracranial DAVF patients were examined using Siemens DSDECTA and cerebral digital subtraction angiography (DSA). Imaging data were retrospectively analyzed to evaluate the concordance between the imaging modalities. Results: DSDECTA examination showed that the blood-supplying arteries were thickened and the draining veins and dural sinuses were expanded in all 9 patients. The presence and characteristics of intracranial DAVF were confirmed using DSA. Head CT showed subarachnoid hemorrhage in 4 cases and intracerebral hematoma in 3 cases. Conclusion: Although DSA is the gold standard for DAVF diagnosis, DSDECTA is less invasive and more suitable for revealing the three-dimensional structure of secondary intracranial lesions as well as other DAVF characteristics. Thus, DSDECTA may be a new alternative for noninvasive screening of suspected DAVF patients before interventional embolization and surgical resection.

Keywords: Dural arteriovenous fistula, dual-source dual-energy CT angiography, digital subtraction angiography, subarachnoid hemorrhage, intracerebral hematoma

Introduction

Dural arteriovenous fistula (DAVF), also known as dural arteriovenous malformation (DAVM), refers to an aberrant connection between arteries and veins crossing the dura mater and its appendages the falx cerebelli and tentorium cerebelli. DAVF accounts for 10%-15% of all intracranial vascular malformations, and can occur in any part of the dura mater, but most frequently in the transverse sinus, sigmoid sinus, cavernous sinus, and tentorium cerebelli. Digital subtraction angiography (DSA) is the current gold standard for diagnosis of DAVF and an important imaging method for preoperative evaluation. The recently developed dual-source dual-energy computed tomography angiography (DSDECTA) has several advantages over conventional CT angiography, specifically higher temporal resolution and better material (tissue) resolution at a given total radiation dose. Indeed, DSDECTA has proven effective for the early detection and accurate diagnosis of intracranial vascular lesions [1-4]. In

this study, we evaluated the clinical utility of DSDECTA for DAVF diagnosis by retrospectively reviewing imaging results in a patient cohort examined by both DSDECTA and DSA.

Materials and methods

Clinical data

This study cohort consisted of 9 patients (5 males and 4 females, mean age 41.6 years, range 28-64 years). Clinical symptoms were recurrent headaches, nausea, and vomiting in 6 cases, spontaneous subarachnoid hemorrhage in 4 cases, intracranial hematoma in 3 cases, epilepsy in 3 cases, facial and scalp exposure or engorgement in 4 cases, sudden severe tinnitus in 3 cases, and unconsciousness in 3 cases. According to the DAVF classification proposed by Cognard et al [5], 2 cases were type I, 3 cases were type II, 3 cases were type III, and one case was type IV. All patients provided written informed consents for inclusion of clinical data in this study.

Dual-energy CT angiography in intracranial dural arteriovenous fistula

Table 1. Patient demographic and clinical data

Patient	Age (y)	Sex	Clinical Presentation	Feeding Arteries	Drainage Veins	Fistula Location
1	28	F	SAH, nausea, vomiting	MMA	CV	Anterior cranial fossa
2	29	M	PT, intracranial hematoma	OA, MMA	CV	Anterior cranial fossa
3	33	M	PT	MMA	OV	Anterior cranial fossa
4	64	M	Intracranial hematoma	MMA	OV, IPS	Cavernous sinus
5	53	M	SAH, PT	MMA	OV, IPS	Cavernous sinus
6	31	F	SAH, nausea, vomiting	MMA	OV	Anterior cranial fossa
7	44	M	SAH, nausea, vomiting	OA, MMA	OV, EJV, IPS	Cavernous sinus
8	56	F	Intracranial hematoma	APA, Occ	CV	Superior sagittal sinus
9	36	F	Recurrent headaches	OA, STA	OV	Superior sagittal sinus

Notes: SAH, spontaneous subarachnoid hemorrhage; PT, pulsatile tinnitus; OA, ophthalmic artery; MMA, middle meningeal artery; SSS, superior sagittal sinus; Occ, occipital artery; OV, ophthalmic vein; CV, cortical vein; EJV, external jugular vein; APA, ascending pharyngeal artery; STA, superficial temporal artery; IPS, inferior petrosal sinus.

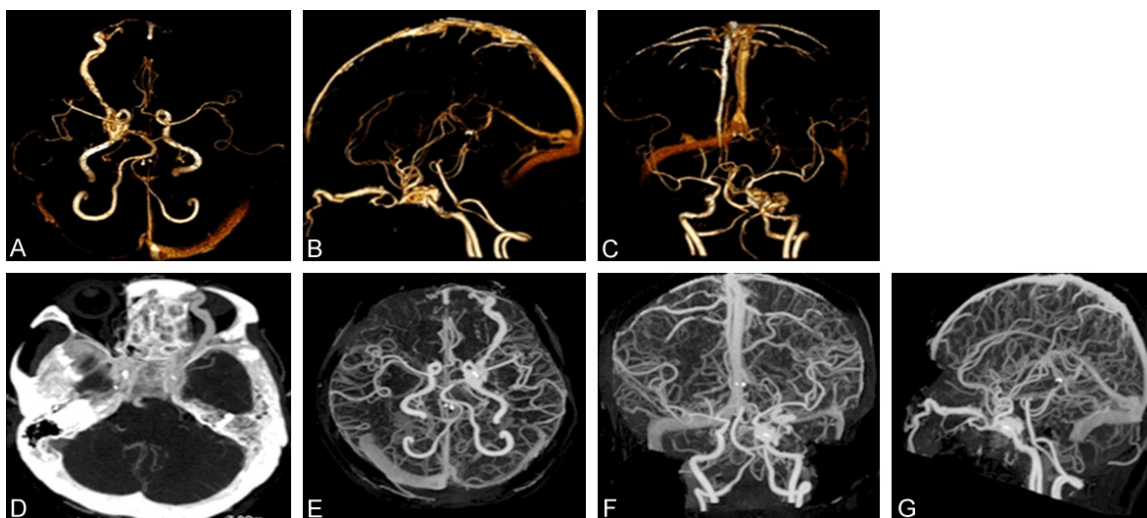


Figure 1. A-G. Neurovascular imaging of a patient with cavernous sinus type DAVF by dual-energy CT angiography (DECTA). The left cavernous sinus was densely stained by contrast agent. Blood was supplied to the fistula by the external carotid artery and the middle meningeal artery, drained forward to the superior ophthalmic vein, which was significantly enlarged and tortuous, drained downward to the facial veins, and drained backward to the superior and inferior petrosal sinuses. Panels A, B, and C are DECTA images in the axial, sagittal, and coronal planes with volume rendering. Panel D is a DECTA image in the axial plane with multiplanar reconstruction. Note the thickened tortuous left superior ophthalmic vein. Panels E, F, and G are DECTA images in the axial, sagittal and coronal planes with maximum intensity projection.

Imaging data

All patients were examined by conventional cranial CT with a pitch of 6.0 mm, by DSDECTA, and by DSA for confirmation.

DSDECTA and image reconstruction

A Siemens dual-source spiral CT with dual-energy was used for examination. The patient lay first in the supine position with head fixed and eyes in orthophoria and then in both lateral positions for cranial CT and enhanced helical scans. Enhanced scanning parameters were as

follows: tube A, 140 kV and 50 mA; tube B, 80 kV and 230 mA; detector, 64 mm × 0.6 mm in width; tube rotation time of 0.33 s, and pitch of 0.7 mm. Scanning was performed from the aortic arch upward to the head. If only intracranial lesions were suspected, the scanning range was C2 level to the head. An 18-gauge intravenous catheter attached to a high-pressure syringe (MEDRAD, Warrendale, PA) was placed in the cubital vein and 60~75 mL iopamidol (370 mgI/mL) injected as a contrast agent, followed by 20~30 mL normal saline at 4~5 mL/s. The CT threshold value was set to 100 Hu for

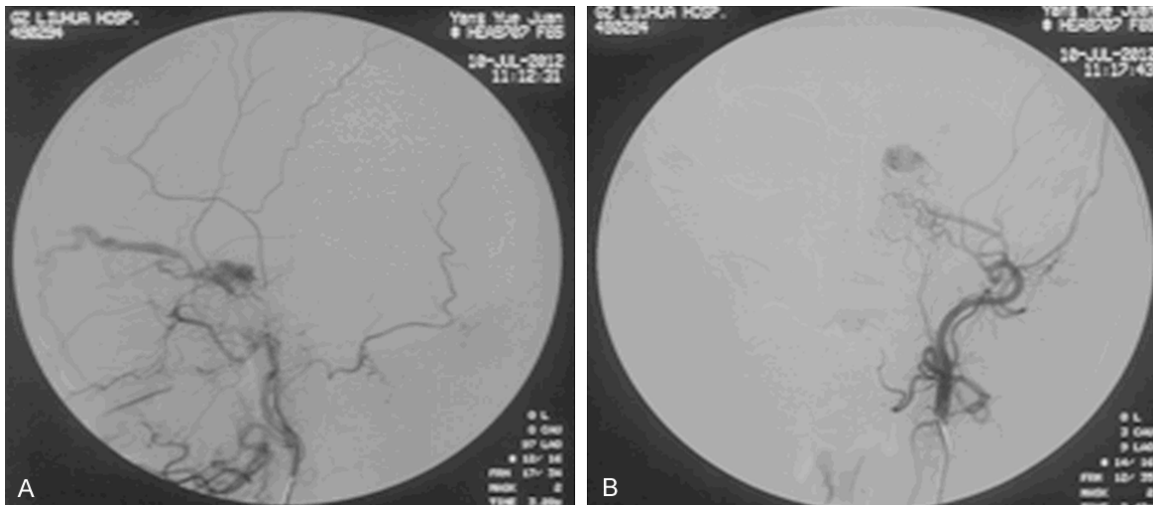


Figure 2. A, B. Neurovascular imaging by DSA (same patient as in **Figure 1**). DSA images acquired in orthophoria and lateral positions. Whole brain DSA scans also show left cavernous sinus type DAVF, in accordance with DECTA. Left carotid artery angiography reveals that the left internal maxillary artery is thickened and communicated by the middle meningeal artery and the ipsilateral cavernous sinus. The left cavernous sinus is developed early in the arterial phase. Blood is drained forward to the superior ophthalmic vein, downward to the facial veins, converges at the left external jugular vein, and is drained backward to the superior and inferior petrosal sinuses.

triggering. The plane of interest was positioned in the ascending aorta.

Images were reconstructed from 1-mm thick scans with 0.3-mm overlap using the reconstruction function D30f. Three sets of data obtained by scanning were transferred to a Siemens dual-source CT professional post-processing workstation (Syngo CT Workplace, version Syngo 2008). To clearly reveal the anatomic structure of blood vessels, dual energy software was used to remove bones. The boneless image software Inspace was used to reconstruct three-dimensional images by volume rendering (VR), maximum intensity projection (MIP), multiplanar reconstruction (MPR), and curved planar reconstruction (CPR), as well as for rotation and adjusting the tissue-removal threshold for three-dimensional (3D) synthesis.

Cranial DSA

Routine examination and 3D DSA were performed using the LCV digital subtraction system (GE, U.S.). The conventional surgery area was prepared and draped, and the right femoral artery punctured using the Seldinger technique under local anesthesia. A 5F arterial sheath was inserted, through which a 4F VER imaging tube was fed, and the left and right internal carotid arteries and the left vertebral

artery were examined by DSA. Contrast agent was administered in successive 6-mL injections at 4.0 mL/s. Photographs were taken in the orthophoria, lateral, and double oblique positions (left and right anterior oblique positions at 45°).

DSDECTA and DSA images of the skull base and intracranial vessels were jointly evaluated by two experienced radiologists and neurosurgeons to determine the presence, number, size, and distribution of fistulae, and the relationship between fistulae and surrounding anatomical structures, thus providing the basis for surgical approaches and methods. Disagreements were resolved by consultation until consensus was reached.

Results

Brain examination using DSDECTA revealed that all 9 patients with DAVF exhibited thickening of the blood-supplying arteries and expansion of draining veins and dural sinuses. In some patients, blood was drained onto the cerebral surface or into intracranial veins to form a venous network. These observations were confirmed by DSA, and the coincidence rate of DECTA with DSA was 100%. In 4 patients with fistula in the anterior skull base (Patients 1, 2, 3, and 6 in **Table 1**), the blood was supplied by the ophthalmic artery and its main

branches and by the middle meningeal artery, drained mostly by the cortical vein, and refluxed to the superior sagittal sinus. In 2 patients with DAVF in the cavernous sinus (Patients 4 and 5, **Table 1**) the blood was supplied mainly by the middle meningeal artery. In 2 patients (Patients 8 and 9, **Table 1**), the blood was refluxed to the cavernous sinus and superior ophthalmic vein. In another (Patient 7), the blood was refluxed to the cavernous sinus, ophthalmic vein, facial vein, and external jugular vein. In the superior sagittal sinus of one patient, blood was supplied by the internal and external carotid arteries, and refluxed to the superior sagittal sinus. Cranial CT scan showed subarachnoid hemorrhage in 4 cases (Patients 1, 5, 6 and 7) and intracerebral hematoma in 3 cases (Patients 2, 4, and 8).

In one patient (**Figure 1** and **Table 1**), the left cavernous sinus was densely stained by contrast agent; blood was supplied by the external carotid artery and the middle meningeal artery, drained forward to the superior ophthalmic vein, which was significantly enlarged and tortuous, drained downward to the facial veins, and drained backward to the superior and inferior petrosal sinuses. Whole brain DSA of the same patient (**Figure 2**) yielded similar results. Left carotid artery angiography showed that the left internal maxillary artery was thickened and communicated by the middle meningeal artery and the ipsilateral cavernous sinus. The left cavernous sinus was developed early in the arterial phase, and blood was drained forward to the superior ophthalmic vein (which again appeared enlarged and tortuous), downward to the facial veins and left external jugular vein, and backward to the superior and inferior petrosal sinuses.

Discussion

Imaging diagnosis of dural arteriovenous fistula

By revealing the type and location of dural arteriovenous fistulae, the blood-supplying arteries, draining veins, flow directions, circulatory disorders, and arteriovenous shunts, angiography is invaluable for explaining clinical symptoms, determining prognosis, and for therapeutic guidance, including surgical planning. Currently, DAVF is diagnosed based on clinical symptoms, signs, and imaging, mainly DSA assisted by CT,

CTA, 3D-CT, magnetic resonance imaging (MRI), and (or) MRA [6]. DSA can reveal the blood-supplying arteries, site, size, and type of fistula, drainage veins and sinuses, the direction of drainage, blood flow velocity, intracranial steal, and possibly dangerous vascular anastomoses. While considered the most valuable method of diagnosis, fluoroscopic examination is invasive and may be rejected by patients [7]. Color Doppler flow imaging is a useful adjunct for DAVF diagnosis, and MRI can reveal fistula next to dural sinuses and the presence of a "flow void" suggestive of DAVF. An alternative noninvasive screening method is MRA, which can reveal the blood-supplying arteries, the direction of draining veins, the sites of fistulae, and the condition of surrounding brain tissue without using contrast agent or inducing radiation injury, but it is difficult to show the branches of small blood vessels, and this modality has some limitations in displaying fistulae.

The flow capacity of cortical draining veins is an important factor determining the course and prognosis of DAVF. Expansion of cortical draining veins (showing flow void signals), extensive edema, and enhancement of brain tissues on MRI are indicative of high risk DAVF. Both T2-weighted MRI and MRA can show abnormal thickening of the blood-supplying arteries and dilation and tortuosity of draining veins for determining the site of the fistula. Moreover, both modalities can simultaneously detect intracranial hemorrhage, cerebral edema, venous sinus thrombosis, hydrocephalus, brain atrophy, and other complications, thus compensating for the limitations of conventional X-ray angiography and providing a basis for comprehensive evaluation of lesions [8]. Bink et al. [9] evaluated 19 DAVF patients and 19 non-DAVF patients using the same sequences of 3T MRI, including 3D time-of-flight (TOF) MRA and time-resolved contrast-enhanced MRA. The results demonstrated that DAVF can be detected with high sensitivity, specificity, and accuracy by experienced radiologists. However, MRI has limitations for the evaluation of DAVF grading and identification of vascular structures, particularly limited resolution and the inability to selectively display arteries. As a result, accurate identification and grading from MRI images is highly dependent on the experience of the viewer. Thus, while MRI/MRA can effectively detect DAVF, it cannot completely replace DSA as yet, especially for treatment planning.

Dual-energy CT angiography in intracranial dural arteriovenous fistula

Diagnostic values and advantages of EDCTA for dural arteriovenous fistula

Computed tomography angiography has become an important screening method for cerebrovascular diseases. In particular, the advent of subtraction CTA has eliminated the interference of the skull base bones, and greatly improved the detection of skull base lesions [10]. However, revealing head and neck blood vessels by subtracting images obtained before and after enhancement requires the patient to remain immobilized. Even slight head movements can cause spatial mis-registration, poor subtraction, and decreased image quality. In contrast, one DSDECTA scan yields two sets of data directly showing the images of blood vessels with removal of bony structures, including vascular calcified plaques. Thus, DSDECTA may be especially suitable for evaluating patients with acute conditions or irritability [11]. A previous comparison of intracranial arterial recombinant images acquired by conventional subtraction CTA and dual-energy CTA found that dual-energy CTA yielded images of slightly lower quality, but there was no difference in lesion identification using these two CTA modalities [11]. It was concluded that dual-energy CTA has diagnostic accuracy comparable to DSA, suggesting that the diagnosis of cerebrovascular diseases by DSDECTA is feasible. In the present study, DSDECTA was used to diagnose 9 DAVF patients, and with various post-processing methods clearly revealed the site and size of the fistula, the abnormal expansion of intracranial veins and scalp veins, and the openness of the circle of Willis.

Clinical data has also shown that DECTA has high concordance rate with DSA for detection of various head and neck vascular diseases [12]. In our group of patients, the concordance of DSDECTA with DSA was 100%. The greatest advantages of DSDECTA are that data is obtained in a single session (reducing sources of error such as movement artifacts), image quality is high, and scanning radiation dose is low. The dual-energy technique can obtain tissue characteristic profiles and iodine distribution according to the attenuation characteristics, thereby providing more information for diagnosis. Dual-source CT consists of two tubes and two corresponding detectors located vertically in the scanner gantry that collect two sets of data, thereby reducing the time for

image reconstruction by half compared to conventional spiral CT. Under dual-source CT, patients receive lower doses of radiation. Hausleiter et al. [13] reported that patients received about 42% less irradiation during dual-source CT than during a 16-slice and 64-slice single-source CT examination.

CTA and DSA in diagnosis of DAVF

Plain and enhanced head CT scans seldom directly detect DAVF, but rather show some of the associated secondary changes, such as venous sinus thrombosis, acute and sub-acute subarachnoid hemorrhage, subdural hemorrhage, brain parenchymal hemorrhage, hydrocephalus, and vascular impressions of the skull plate. In our patient cohort, cranial CT scan showed subarachnoid hemorrhage in 4 cases and intracerebral hematoma in 3 cases. The manifestations of DAVF at different sites on CT are quite different. In cavernous sinus type DAVF, found in two patients, the fistula was located on the cavernous sinus wall, was small in size with little blood flow, was supplied by the middle meningeal artery via the external carotid, and drained via the superior ophthalmic vein, facial veins, and superior and inferior petrosal sinus veins. The fistula had little effect on the distribution of intracranial blood flow and resulted in few secondary intracranial changes. Nonetheless, there were characteristic manifestations. In orbital thin-slice CT scans, orbital tissue proliferation and exophthalmos were visible.

Multi-slice CT techniques continue to improve, with rapid volumetric scanning and new software for 3D rendering. Indeed, head and neck CT angiography is highly effective for the early detection and accurate diagnosis of head and neck artery lesions, and use for such purposes continues to increase [14]. It is noninvasive, requiring only intravenous injection of contrast agent. In addition, CT angiography is simple, fast (10 s for each scan series), safe due to lower radiation, and inexpensive, costing only 1/3 or 1/4 that of DSA. In this group of patients, DSDECTA was used to reconstruct 3D images of the cerebrovascular and arteriovenous fistula. These images, which can be reconstructed at any angle, provide valuable information for planning the optimal surgical approach. In contrast, operation of DSA is relatively more complex, is invasive, and requires higher x-ray and

contrast agent doses. While blood vessels are revealed with clarity, DSA does not yield much information about the surrounding structures. In DAVF patients with cortical venous drainage, head CT angiography can show thickening of dotted and striped arteries supplying blood to the cerebral fistula, the scattered distribution, dilation, and tortuosity of venous confluence in cerebral cortex, and the widening of lateral vascular impressions inside the skull in the bone window settings. However, DSA cannot display all the blood-supplying arteries, draining veins, and cannot provide information on the relationship of DAVF with the surrounding bone structure. CT angiography can show abnormal thickening of the blood supplying arteries and dilation of veins and dural sinuses, but it cannot clearly show the fistula conditions, or small/thin blood-supplying arteries.

Simple CT angiography cannot provide hemodynamic information, so we advocate a combination of imaging modalities. For patients for whom interventional embolization has failed, have experienced recurrence, cannot undergo embolization again, or require surgical treatment for unsuccessful embolization, fistula resection by CT angiography has provided a new treatment option.

DAVF is prone to misdiagnosis due to its complex etiology and diverse clinical manifestations, and is seldom revealed directly by conventional CT or enhanced CT. Rather, DAVF is suggested by the presence of secondary changes. Dual-energy CT angiography can show abnormal thickening of the blood-supplying arteries, dilation of refluxing veins and dural sinuses, and the three-dimensional relationships among fistulae and surrounding tissues. Therefore, it can be used as an alternative to DSA for the non-invasive screening of DAVF and surgical planning for embolization or surgical resection.

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Disclosure of conflict of interest

None.

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Dual-energy CT angiography in intracranial dural arteriovenous fistula

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