Fusion image of subtracted and nonsubtracted rotational angiography for pretherapeutic evaluation of angioarchitectures of dural arteriovenous fistulas

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Purpose

Intracranial dural arteriovenous fistulas (DAVFs) can cause various symptoms from tinnitus to fatal cerebral hemorrhage (1). Aggressive symptoms are related to the drainage pattern of the DAVFs, and the DAVFs with cortical venous drainage should be aggressively treated (2). A majority of cases with symptomatic and/or high risk DAVFs has been treated by endovascular techniques, including transarterial embolization and/or transvenous embolization (1). Precious evaluation of angioarchitecture including feeding arteries, shunted pouches, and draining vein of DAVFs by angiography is essential for successful result. However, it would be difficult to demonstrate these angioarchitectures in details on 2D-DSA in some cases due to overlapping of vessels. Recent developments in three-dimensional angiography technology allow us to evaluate the angioarchitecture of DAVFs more easily and precisely (3) (4). Furthermore, according to recent advances in 3D workstations, several types of fusion images between the different imaging datasets have been widely used (5) (6). In this study, we evaluate clinical utility of a novel imaging technique that fuses 3D subtracted and non-subtracted rotational angiography for pretherapeutic evaluation of angioarchitectures of intracranial DAVFs.
Methods and Materials

We retrospectively analyzed 15 consecutive patients with intracranial DAVFs who underwent rotational cerebral angiography and were subsequently treated between August 2010 and November 2012. Characteristics of the 15 patients were summarized in Table 1. The patients' ages ranged from 41 to 80 years (mean age, 63 years), and there were 9 males and 6 females. In one patient with transverse-sigmoid sinus (TSS) DAVFs, another DAVFs developed at the superior sagittal sinus after the TSS DAVFS cured by transvenous embolization during this period. Therefore, 16 DAVFs were reviewed in this study. The DAVFs were located at the TSS (n=10), the cavernous sinus (n=2), the superior petrosal sinus (n=1), the superior sagittal sinus (n=1), tentorium (n=1), and anterior cranial fossa (n=1). There were 3 type I DAVFs, 2 type IIa DAVFs, 3 type IIa +b DAVFs, 6 type IIb DAVFs, and 2 type II DAVFs according to Cognard's classification of venous drainage of the DAVFs (2). Three lesions were treated by transarterial embolization with glue, and 7 lesions were treated by transvenous embolization of sinus packing (n=3) or selective embolization of the shunted pouches (n=4). The 5 lesions were treated by selective transvenous embolization combined with transarterial embolization with diluted NBCA-lipiodol mixture. The remaining 1 patient with type I TSS DAVFs was followed without treatment.

Biplane selective digital subtraction angiography (DSA) of bilateral internal and external carotid arteries and the vertebral arteries were performed in all patients using biplane angiography equipment (Infinix VB, Toshiba Medical, Tokyo). Rotational DSA was performed when AVFs were found on biplane selective angiography of each cerebral artery. The rotational angle was 200°, and the rotational speed of the C-arm was 50°/second. Data were acquired in a 512 × 512 matrix using an 8-inch field-of-view flat panel detector. A nonionic iodinated contrast material (iopamidol, Iopamiron 300; Bayel HealthCare Japan, Osaka) was injected at a flow rate of 1.5-3.5 mL/sec (14-24.5 mL of total volume) through an automatic injector, and the injection was initiated 1.5-2.0 seconds before the rotation. Three-dimensional (3D) images were reconstructed from a data set of rotational angiography using a workstation (Advantage Workstation, GE Healthcare Milwaukee; Ziostation, Ziosoft, Tokyo). 3D vascular images (3D-DSA) were also reconstructed from a rotational DSA data set built by subtracting mask images from the contrast images. Then, 3D fusion angiographic images were obtained by fusing the 3D-digital angiography (nonsubtracted) and 3D-DSA data sets using the same workstation without registration operation within 5 seconds (Fig. 1). Three types of reconstructed images of maximum intensity projection and volume rendering reconstruction, MPR images can be available.

All angiographic images and partial MIP and MPR images of 3D digital angiography and 3D fusion angiography were reviewed by two experienced neuroradiologists (H.K. and S.T.) with consensus. Selective venography during transvenous embolization was also reviewed when available. The visualization of angioarchitectures of DAVFs including
feeding arteries, shunted pouches and draining veins was comparatively evaluated between 3D digital angiography and 3D fusion angiography. A shunted pouch was defined as a tubular or elliptical vascular structure that is separated from the main sinus lumen into which multiple feeding arteries converge and that continues to main sinus lumen.

Institutional review board approval is not required for such a retrospective study at our institution.
**Fig. 1:** 3D fusion angiographic images (3DFA) are obtained by fusing the datasets of 3D-digital angiography (3DDA) and 3D-digital subtraction angiography (3DDSA) which are reconstructed from rotational digital angiography and rotational DSA by using a modified Feldkamp method.

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Results

MPR and partial MIP images of 3D-fusion angiography clearly demonstrated feeding arteries, shunted pouches, and draining vein in all but one patient. Regarding the visualization of feeding arteries, small feeding arteries running very closely to the bony structure or trasosseously could be depicted on 3D fusion angiography more clearly than 3D digital angiography in 10 lesions (Fig. 2-8) (Fig. 9-16) (Fig 24-27). In 5 lesions, feeding arteries were well depicted on both 3D fusion angiography and 3D digital angiography. In the remaining 1 lesion in a patient who showed disturbance of consciousness caused by TSSDAVFs at angiographic examination, some of the small feeding arteries could not be well evaluated on 3D fusion images due to motion artifact. Shunted pouches were well depicted on both 3D fusion images and 3D digital angiography images in 14 lesions (Fig. 17-23), and more clearly visualized on 3D fusion images in 2 lesions which were located at the superior petrosal sinus and the TSS. For the draining vein, a tiny draining vein of the inferior temporal vein from the TSS DAVFs could be demonstrated on 3D fusion images but not on 3D digital angiography. In the other 15 lesions, draining veins were well demonstrated on both 3D fusion images and 3D digital angiography images.
**Fig. 1:** 3D fusion angiographic images (3DFA) are obtained by fusing the datasets of 3D-digital angiography (3DDA) and 3D-digital subtraction angiography (3DDSA) which are reconstructed from rotational digital angiography and rotational DSA by using a modified Feldkamp method.

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Fig. 2: Left transverse sigmoid sinus DAVFs (type I) with a shunted pouch at the transverse-sigmoid junction. a, b: Frontal (a) and lateral (b) views of the left external carotid angiography showing DAVFs at the transverse-sigmoid junction. The DAVFs are fed by the posterior convexity branch, the petrosquamous branch and the petrosal branch of the middle meningeal artery, jugular branch of the ascending pharyngeal artery and the transosseous branches of the right occipital artery, and drain antegrade into the sigmoid sinus. c: Axial reformatted images of the 3D digital angiography of the left external carotid artery showing a shunted pouch (S) that is located medially to the transverse-sigmoid junction. The shunted pouch was fed by the petrosal branch (white arrows) and the petrosquamous branch (white arrowhead) of the middle meningeal artery. Continuity of the petrosal branch of the middle meningeal artery is not clearly demonstrated. d: Axial reformatted images of the 3D fusion angiography of the left external carotid artery at the same levels of (c) clearly show the shunted pouch (S) and its feeding arteries including the petrosal branch (white arrows), the petrosquamous branch (white arrowhead) of the middle meningeal artery, and transosseous branches (arrows) of the occipital artery. Continuity of the petrosal branch (white arrows) of the middle meningeal artery is well depicted. e: Fluoroscopic image during selective transvenous embolization shows coils placed in the shunted pouch (arrow). f, g: Left common carotid angiography, lateral view at arterial phase (f) and frontal view at venous phase (g) after selective transvenous embolization of the shunted pouch showing the disappearance
of the DAVFs with preservation of the left transsigmoid sinuses. A filling defect at the transsigmoid junction (arrow in g) represents the shunted pouch packed with coils.

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**Fig. 3:** Axial reformatted images of the 3D digital angiography of the left external carotid artery showing a shunted pouch (S) that is located medially to the transverse-sigmoid junction. The shunted pouch was fed by the petrosal branch (white arrows) and the petrosquamous branch (white arrowhead) of the middle meningeal artery. Continuity of the petrosal branch of the middle meningeal artery is not clearly demonstrated.

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**Fig. 4:** d: Axial reformatted images of the 3D fusion angiography of the left external carotid artery at the same levels of (c) clearly show the shunted pouch (S) and its feeding arteries including the petrosal branch (white arrows), the petrosquamous branch (white arrowhead) of the middle meningeal artery, and transosseous branches (arrows) of the occipital artery. Continuity of the petrosal branch (white arrows) of the middle meningeal artery is well depicted.

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**Fig. 5: e** Fluoroscopic image during selective transvenous embolization shows coils placed in the shunted pouch (arrow).

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Fig. 6

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**Fig. 7:** Figure 3 Left transvers sinus DAVFs (type IIa+b) with right sigmoid sinus occlusion a: Lateral views of the left external carotid angiography showing DAVFs diffusely involving the left transverse-sigmoid sinuses. The DAVFs are mainly fed by the numerous transosseous feeders from the left occipital artery. b: Sagittal reformatted images of 3D fusion angiography of the left external carotid artery showing multiple shunted pouches (white arrows) that are located dorsally to the distal transverse-sigmoid sinuses. The shunted pouches were fed by numerous transosseous branches of the occipital artery. c, d: Frontal view (e) and lateral view (f) of the right external carotid artery showing DAVFs at the sinus confluence fed by multiple branches of the occipital artery and the jugular branch of the ascending pharyngeal artery. The DAVFs drains retrograde into the cortical veins and the superior sagittal sinus. e: Sagittal reformatted images of 3D fusion angiography of the right external carotid artery showing shunted pouches (S1 and S2). Numerous transosseous branches of the occipital artery converge to a shunted pouch (S2). Feeding arteries from the ascending pharyngeal artery continued to another shunted pouch (S1) located ventrally to the S1. f: Selective venography of the shunted pouch located dorsally to the left transverse sinus showing a microcatheter located in the shunted pouch shown on the 3D fusion image (b). Each shunted pouch was occluded with coils. g: Selective venography of the shunted pouch located adjacent to the sinus confluence showing a microcatheter located in the shunted pouch (S2) shown on the 3D fusion image (e). The shunted pouches were partially
occluded with coils. h: Selective angiography with contrast injection via a microcatheter showing the micocatheter placed close to the shunted pouch (S1 on e) through the ascending pharyngeal artery. i: Selective venography showing a microcatheter advanced transvenously into the same shunted pouch (S1). The shunted pouch was embolized transvenously with coils, and then transarterially with glue. j: Right external carotid angiography after selective transvenous embolization and transarterial embolization showing minimal residual DAVFs. Retrograde cortical and sinus reflux were disappeared.

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Fig. 14

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Fig. 15: Figure 4 Left superior petrosal sinus dural arteriovenous fistulas (DAVFs) presented with a small cerebellar hemorrhage. a: Lateral view of the left external carotid angiography showing DAVFs involving the superior sagittal sinus. The DAVFs are fed by the accessory middle meningeal artery (arrows) and drain into the left cavernous sinus. b: Lateral view of the left vertebral angiography showing the DAVFs fed by the small feeding arteries from anterior inferior cerebellar artery which originates from a common trunk with the posterior inferior cerebellar artery. c: The axial reformatted images of 3D digital angiography of the left external carotid artery show multiple small feeders (double white arrows) around the superior petrosal sinus. The shunted pouches and continuity of the feeding arteries with the accessory meningeal artery (single white arrow) is not clearly demonstrated. d: The axial reformatted images of 3D fusion angiography of the left external carotid artery show multiple small feeders originating from the accessory meningeal artery (white arrows) and converging to a shunted pouch (S). e: The axial reformatted images of 3D digital angiography of the left vertebral artery show small feeders (white arrow) originating from the anterior inferior cerebellar artery converging to a shunted pouch. The AVF draining into the cavernous sinus (CS). f: The axial reformatted images of 3D fusion angiography of the left vertebral artery demonstrated the shunted pouch more clearly. Drainage routes into the cavernous sinus (CS) and the transverse sinus are also more clearly demonstrated. The DAVFs were treated by
selective transvenous embolization. e: Fluoroscopic image during selective transvenous embolization shows coils placed in the shunted pouch.

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Fig 4f

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Fig. 22: Figure 5 Right transvers sinus DAVFs (type Ila) treated by selective transvenous and transarterial embolization. a: Lateral views of the right middle meningeal angiography showing DAVFs involving the right transverse-sigmoid sinuses. The DAVFs are fed by the posterior convexity branches, the petrosquamous branch and the petrosal branch. Selective transvenous embolization of the shunted pouch at the transverse sigmoid junction was performed at first, and then transarterial embolization with glue was subsequently performed. b: Selective angiography during injection of glue via the posterior convexity branch shows glue filled into the residual space of the shunted pouch packed with coils. c: Selective angiography after embolization shows small residual DAVFs fed by small petrosal branches of the middle meningeal artery. d,e: Axial (a) and sagittal (b) partial MIP images of 3D fusion angiography of the right external carotid artery showing the residual feeder (arrows) of the middle meningeal artery running through the facial nerve canal and anastomosing with the stylomastoid artery (arrowhead) from the occipital artery. These residual DAVFS were not treated because of the dangerous feeding artery. S: shunted pouch, FS: foramen spinosum

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Endovascular treatment, including transarterial embolization and transvenous embolization, has become the first-line option for the treatment of most cases of intracranial DAVFs. Recent reports of transarterial embolization using liquid embolic materials such as ONYX and glue showed high curative rates of DAVFs especially for Cognard's type IIb and type III DAVFs (7) (8). However, serious complications including cranial nerve injury, distal migration, and embolization of cerebral arteries due to migration of glue via the dangerous anastomosis have also been reported (9-11). Therefore, it is very important to evaluate the feeding arteries and the fistulous points for avoiding such complications. Transvenous embolization is an effective technique for the treatment of sinusal DAVFs especially for cavernous sinus DAVFs. Sinus packing with coils has been used as a standard technique for the treatment of sinusal DAVFs. Recently, several authors demonstrated effectiveness of selective transvenous embolization of the shunted pouches for the selected cases (12) (13). Evaluation of the fistulous points, shunted pouches and small draining vein is required for transvenous embolization. Serious complication such as cerebral hemorrhage can occur during and after transvenous embolization when the DAVFs remain with retrograde drainage via a small cerebral vein (14) (15). Therefore, evaluation of their angioarchitectures including feeding arteries, shunted pouches, and draining veins before treatment is very important for successful results. Biplane DSA has been use as a gold standard technique for evaluating angioarchitectures and hemodynamics of DAVFs. However, 2D DSA of carotid artery cannot clearly demonstrate the angioarchitectures in some cases due to overlapping of numerous vessels enlarged due to arteriovenous shunt. It has been reported that CT-like images reconstructed from a data set of rotational digital angiography are useful for evaluating these angioarchitectures (3) (4). Hiu et al. demonstrated the superiority of CT-like images to 2D-DSA in assessing these angioarchitectures of DAVFs (4). However, it would be sometime difficult to evaluate small vessels running adjacent to or within the bony structure due to similar density of the enhanced vessels and bone. In our results, 3D fusion images were superior to 3D-digital angiography (CT-like images) for evaluating angioarchitectures of DAVFs in a majority of case. 3D fusion images showed much better results especially for depiction of a small transosseous feeders or small feeders running very close to the thick bone (eq.petrosal bone). MIP and/or MPR reconstructed images from single dataset of rotational DSA (3D-DSA) can demonstrate these small branches, while orientation and identification of these branches are more difficult due to lack of osseous images. Recently, a report describing a technique of 3D fusion images between data sets of mask images and DSA images during rotational DSA (16). However, clinical efficacy of the 3D fusion images has not been reported. In our technique of 3D fusion images, we fused datasets of nonsubtracted and subtracted digital angiography. This technique can enhance the vascular structure more than the fusion image obtained from datasets of mask images and rotational DSA, and therefore tiny vascular structure can be visualized. In our clinical experiences, pretherapeutic evaluation of the angioarchitectures of DAVFs using the 3D-fusion images
is very useful for endovascular treatment. For transarterial embolization, dangerous feeder and potential anastomoses could be identified well and easily grasped by 3D fusion images. For transvenous embolization, small shunted pouches could be precisely depicted, and it was useful for selective embolization of these shunted pouches.

In our series, small vessels could not be well visualized due to motion artifact in one patient with conscious disturbance. Because DSA based data is used in this technique, patient's motion during obtaining mask data and angiographic data spoil the image quality. It is one limitation of this technique.

In conclusion, fusion images of non-subtracted and subtracted rotational angiography are useful for pretherapeutic evaluation of angioarchitectures of intracranial DAVFs.
References


