Flat Detector Computed Tomography-Based "Dual Vessel Fusion" Technique for Diagnosis and Surgical Planning in the Management of Dural Arteriovenous Fistula

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■ OBJECTIVE: **To explore the value of flat detector computed tomography-based vessel fusion technique for visualizing and evaluating anatomic structures and hemodynamic features of patients diagnosed with dural arteriovenous fistulas (DAVF).**

■ METHODS: **Eleven patients with DAVF were investigated. The 3-dimensional structure of the DAVF fistula point, feeding arteries, and draining veins were reconstructed from separately acquired rotational angiographic images and then displayed as a single image in a fused manner.**

■ RESULTS: **In the vessel fusion image, the tangled cluster of vessels of the DAVF could be clearly visualized from selected optimal viewing angles in the 3-dimensional space. Each component of the DAVF fistula point with its specific artery feedings and venous drainage could be identified accurately.**

■ CONCLUSIONS: **The vessel fusion technique gave detailed anatomic information that enabled better understanding of the DAVF structure, and facilitated an accurate interventional or surgical planning.**

INTRODUCTION

A dual arteriovenous fistula (DAVF) is an abnormal connection between dural arteries and dural venous sinuses, meningeal veins, or cortical veins. DAVFs comprise 10%–15% of all intracranial arteriovenous malformations (2, 8). The clinical manifestations of patients and thier treatment plans are mainly determined depending on the location and the venous drainage pattern. Most DAVFs can be managed by endovascular treatment but some are more appropriately approached by surgery. Precise identification of the anatomic structure of the DAVF, such as the feeding arteries, the draining veins, and especially the location of the fistula point, and assessment of hemodynamic features of the fistula are essential to a successful treatment. At present, there are several imaging modalities and techniques for diagnosing DAVFs such as noninvasive computed tomography angiography and magnetic resonance imaging angiography. These imaging techniques are particularly useful in localization of the arteriovenous shunt in relation to the surrounding brain tissue and skull anatomy, and are suitable for DAVF primary diagnosis and follow-up examination. However, these techniques, limited by their spatial resolutions, lead to an inadequate presentation of the detailed structure of the DAVF (1, 5, 6, 10, 14). Flat detector computed tomography (FDCT)-based cerebral digital subtraction angiography (DSA), with a resolution of 0.1–0.2 mm, remains the gold standard for complete characterization and classification of the DAVF (9). This technique involves injecting a certain amount of radiopaque contrast medium (CM) into the arteries of interest through a catheter. At the same time, 2-dimensional (2D) x-ray images are acquired for clinical observation. DAVF may have more than 1 major feeding artery, and thus, injection of all potential arteries needs to be performed to identify component that may contribute to the pathology of the region. However, DAVFs consist of numerous tiny connections between branches of dural arteries and veins or a venous sinus, with their structures varying within the 3-dimensional (3D) space. Thus, with the limited projection angles

Key words
- 3D reconstruction
- Angiography
- DAVF
- Dual vessel fusion

Abbreviations and Acronyms
2D: 2-dimensional
3D: 3-dimensional
CM: Contrast medium
DAVF: Dural arteriovenous fistula
DSA: Cerebral digital subtraction angiography
FDCT: Flat detector computed tomography

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provided by the 2D DSA, an accurate assessment of the DAVF is not guaranteed, which potentially results in treatment failure. Studies have shown that FDCT-based 3D volume reconstructions, which enabled visualization from any angle, have overcome some of limitations of 2D imaging. 2D imaging limitations may include false vessel foreshortening due to an inappropriate projection angle or a vessel obscured by superimposed vessels.

This study was based on the FDCT imaging and explored the value of the state-of-the-art image postprocessing technique "dual vessel fusion" (13) to improve the visualization of the fistula point with 2 arterial feeders and to assist in treatment planning.

METHODS

Patient Data Collection

Between August 2012 and December 2013, 11 patients (5 men and 6 women; mean age, 50.0 ± 11.9 years) were confirmed to have DAVF and were enrolled into this study. This study had been approved by the hospital ethics committee.

Image Acquisitions

Each patient received intravenous sedation plus local anesthesia. All imaging procedures were performed with a biplane FDCT system (Artis zee, Siemens Healthcare, Germany). For each patient, 2D DSA sequences were acquired after catheterization of bilateral external and internal carotid arteries and vertebral arteries in a sequential order. If feeding arteries of the DAVF were detected, a 3D rotational angiography was conducted. To this aim, a 3D mask image was acquired first. Nonionic iodinated CM (300 mg/mL; Bayer Healthcare, Puteaux, France) was then injected into the carotid or vertebral artery supplying the fistula with a power injector (150 psi) with injection rates optimized according to the blood flow of the fistula, and for a duration of 6 seconds. X-ray delay was configured for 1 second after the start of the CM injection to ensure that the vessels were fully contrasted during the image acquisition. The C-arm rotated 200 degrees in 5 seconds, at a speed of 1.5-degree/frame and with an x-ray dose of 0.36 μGy/frame. For each 3D acquisition, 133 projection images were generated, with the total dose of approximately 60 mGy.

Vessel Fusion

After the 3D image acquisition procedure, the projection images in Dicom format were automatically transferred to a dedicated commercial workstation (*syngo* Leonardo XWP, Siemens Healthcare). Advanced techniques ("Dual volume reconstruction" and "*syngo* Inspace 3D/3D fusion", Siemens Healthcare) enabled automatic reconstruction of 3D volume and generation of fusion images by combining each volume data set into 1 window using a volume-rendering technique. Fusion of the 2-image data sets involved using either intensity-based automatic registration or visual matching-based manual registration of 2 sets of 3D angiography pixel data (3). If the automatic registration result was unsatisfactory, manual registration could be used to ensure a precise image fusion result. The skull structure, which was identical in both image data sets, could be selected as the landmark, and then manual adjustment was performed until the 2 volumes were superimposed. The window width and level were adjusted, different pseudo-colors were assigned to the 2-vessel volumes (e.g., red and white). As a result, a volume-rendered fusion image of DAVF, with each individual component of different origins and drainages depicted in a different color, provided intraprocedural image guidance. The fusion image could be rotated, magnified, and the window level settings could be adjusted to achieve an optimized visualization.

To determine whether 2 volumes of vessels were properly fused, anatomic relationships of the vasculature were visually evaluated by an experienced radiologist in all cases. For instance, the match of the fistula point and draining veins in 3D space could be examined, confirming the spatial accuracy of the fusion result.

RESULTS

Successful vessel fusion was achieved for all 11 patients. The vessel fusion image was used to accurately identify the detailed morphology and location of the DAVF. The components of the DAVF, including joint fistula point, different feeding arteries, and draining veins, could be clearly demonstrated in 1 fusion image. The treatment decision between surgery and intervention was made depending on the complexity of reaching the treatment target as well as the possibility to completely embolize the fistula. These results and treatment options for each patient are detailed in **Table 1**.

The merged blood flow stream from 2 distinct feeding arteries, depicted in red and white, could be clearly discerned at the fistula point and in the draining vein as a mixture. The initial merging point of the "red" and the "white" feeding arteries, accurately indicated by the fistula was sometimes challenging to define in the conventional 2D or 3D DSA images. The DAVF, revealed by the fused images, was either of a single (**Figure 1**) or a network-like fistula point (**Figure 2**).

Representative Cases

Case 1. A middle-aged patient presented with intermittent dizziness for 2 months. A 2D DSA revealed the presence of a DAVF located at the frontal skull base with blood supplying from bilateral ophthalmic arteries and draining into an intracranial phlebangioma (**Figure 1A—C**). During the image postprocessing using dual vessel fusion, the 3D angiography of left internal carotid artery was designated as white vessels (**Figure 1D**) and the right internal carotid artery as red vessels (**Figure 1E**). The 2 volumes were then fused into 1 volume with visually confirmed spatial accuracy (**Figure 1F**). In the fused images, the merged blood flow could be seen from the bilateral feeding arteries that then drained into the vein as a mixture of red and white through the fistula. The fistula was clearly defined as the merging point of the 2 feeding arteries (**Figure 1G,H**). This detailed structural information facilitated an accurate surgical plan. The anatomy and formation of the DAVF were verified during surgery (**Figure 1I**). Postoperative 4 dimensional computed tomography angiography showed a successful obliteration of the DAVF, with complete disappearance of the fistula as well as the dilated draining vein (**Figure 1J**).

Case 2. A middle-aged patient suffered from pulsatile tinnitus for 2 years. A 2D DSA showed a network-like DAVF fed by a branch of the right occipital artery (**Figure 2A,B**) and a meningeal branch of the right vertebral artery (**Figure 2C,D**). The 3D angiogram of the