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Four-dimensional computed tomography angiographic evaluation of cranial dural arteriovenous fistula before and after embolization

Bing Tian [1], Bing Xu [1], Jianping Lu *, Qi Liu, Li Wang, Minjie Wang

Department of Radiology, Changhai Hospital of Shanghai, The Second Military Medical University, No. 168 Changhai Road, Shanghai, China

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ABSTRACT

Purpose: This study aimed to evaluate the usefulness of four-dimensional CTA before and after embolization treatment with ONYX-18 in eleven patients with cranial dural arteriovenous fistulas, and to compare the results with those of the reference standard DSA.

Patients and Methods: Eleven patients with cranial dural arteriovenous fistulas detected on DSA underwent transarterial embolization with ONYX-18. Four-dimensional CTA was performed an average of 2 days before and 4 days after DSA. Four-dimensional CTA and DSA images were reviewed by two neuroradiologists for identification of feeding arteries and drainage veins and for determining treatment effects. Interobserver and intermodality agreement between four-dimensional CTA and DSA were assessed.

Results: Forty-two feeding arteries were identified for 14 fistulas in the 11 patients. Of these, 36 (85.71%) were detected on four-dimensional CTA. After transarterial embolization, one patient got partly embolized, and the fistulas in the remaining 10 patients were completely occluded. The interobserver agreement for four-dimensional CTA and intermodality agreement between four-dimensional CTA and DSA were excellent ($\kappa = 1$) for shunt location, identification of drainage veins, and fistula occlusion after treatment.

Conclusion: Four-dimensional CTA images are highly accurate when compared with DSA images both before and after transarterial embolization treatment. Four-dimensional CTA can be used for diagnosis as well as follow-up of cranial dural arteriovenous fistulas in clinical settings.

1. Introduction

A cranial dural arteriovenous fistula (DAVF) is an abnormal direct connection between meningeal arteries and dural sinuses. It is an uncommon but important cause of long-term morbidity and mortality, with an annual neurologic event rate of 15% [1,2]. Transarterial embolization using a liquid embolic agent such as ONYX-18 is an established treatment method for DAVF that has found clinical use in recent years [3]. DSA remains the gold standard for diagnosis and evaluation of DAVF. With its high spatio-temporal resolution, DSA enables DAVF detection, feeding artery visualization, DAVF location, and evaluation of the venous drainage pattern and the treatment effects of embolization. However, DSA is relatively expensive, time consuming, and invasive [4].

MRA, especially time-resolved MRA, has adequate spatio-temporal resolution for vessel disease evaluation, and has been used widely in recent years. It can also be used in the diagnosis and classification of DAVF [5]. The drawbacks of traditional MRA in DAVF diagnosis are its relatively low sensitivity for slow flow shunts and it inability to be used for hemodynamic evaluation [6]. Time-resolved MRA is feature of no radiation and more sensitivity than traditional MRA for hemodynamic evaluation. But some small arterial feeder vessels can be missed by time-resolved MRA due to the partial volume effect at the current spatial resolution and slow flow velocities [1]. CTA is another noninvasive tool used to diagnose intracranial vascular lesions. Whole-brain CT digital subtraction angiography or four-dimensional (4D) CTA has become possible with 320-detector row CT, which allows dynamic display of abnormal vessels in multiple periods, from the very early artery phase to the late venous phase [7]. 4D CTA enables noninvasive dynamic visualization of the entire cranial circulation [8].

The objective of the present study was to conduct 4D CTA in 11 patients with DAVF before and after embolization with ONYX-18 and to compare this technique with the reference standard DSA.

Abbreviations: DAVF, dural arteriovenous fistula; 4D, four-dimensional.

* Corresponding author. Tel.: +86 21 31162146; fax: +86 21 81873637.
E-mail addresses: bing.tian@hotmail.com (B. Tian), aishanli0102@126.com (B. Xu), tianbing2003@163.com, cjr.lujianping@vip.163.com (J. Lu), liuqimd@126.com (Q. Liu), wangli_changhai@163.com (L. Wang), cjr.wangminjie@vip.163.com (M. Wang).

[1] These authors contributed equally to this study.

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2. Patients and methods

The study protocol was approved by the Commission on Scientific Research of Human Subjects of our hospital. Written informed consent was obtained from all patients.

2.1. Patients

Between June 2012 and October 2014, eleven patients (10 men and 1 women whose ages ranged from 18 to 72 years; mean age, 46.36 years) with DAVF were selected for assessment. All patients had been newly diagnosed during the first 4D CTA examination and had undergone transarterial embolization with ONYX-18 after DSA. The interval between the first 4D CTA examination and DSA was an average of 2 days. The second 4D CTA examination was carried out about 4 days after DSA. Exclusion criteria were known allergy to iodinated contrast agents, renal failure (indicated by a baseline serum creatinine level of >133 μmol/L), and lack of informed consent.

2.2. 4D CTA examination

All patients underwent imaging with a 320-multidetector row (640 slices) CT system (Aquilion ONE; Toshiba Medical Systems, Tokyo, Japan), which has a detector width of 16 cm with 320 detector rows. Other scanning parameters were as follows: field of view, 25 cm; slice thickness, 0.5 mm; tube voltage, 80 kV; and current-time product, 120 mAs. For CT imaging, 19 whole-head volume data were acquired at 2 s intervals for the first 14 volumes and at 3 s intervals for the last 5 volumes starting 5 s after bolus injection of 50 mL of iodinated contrast agent (Iopamiro, Bracco Sine Pharmaceuticals, Shanghai, China) at 5 mL/s; then, 20 mL of (0.9%) physiological saline was injected at 4–5 mL/s. The slice thickness of the imaging was 0.5 mm. Digital subtraction of the whole-head volumes was carried out on a display workstation (Vitrea fX ver. 6.0) allowing for subtracted 3D reconstructions and 4D CTA images with 18 phases, including the early arterial, mixed arterial, and late venous phases. The images were generated by using MIP, and if necessary, volume rendering was used to simultaneously evaluate the vessel.

2.3. DSA examination

DSA (Artis zee biplane; Siemens AG, Erlangen, Germany) involved femoral puncture and selective injection of the vessels using Ultravist (5 mL/s, Bayer-Schering, Berlin, Germany). Images were acquired with a 1024 × 1024 matrix, 22-cm field of view, and 0.21 × 0.21 pixel size in the late venous phase with standard anteroposterior, oblique, and lateral views. All examinations included frontal and lateral views with injection of contrast agent in the bilateral internal carotid, external carotid, and vertebral arteries. When indicated, selective injection of the occipital, ascending pharyngeal, and internal maxillary arteries or other branches was also performed. After angiographic evaluation, all patients underwent endovascular treatment with ONYX-18 (ev3, CA, USA). The catheter was advanced to the end of the DAVF feeding artery and ONYX-18 was injected. During injection, we were able to obtain an angiogram to evaluate shunt occlusion and the status of the venous drainage and then continue the injection until the fistula was completely or mostly occluded. Care was taken to remain as close to the fistula as possible to minimize ischemic injury to the cranial nerves during embolization. All examinations included frontal and lateral views of all the internal carotid, external carotid, and vertebral arteries after embolization, whereby the effects of embolization were evaluated. In each views, 60 images were obtained both before and after the treatment, and all the images were performed to be evaluated by the reviewers.

2.4. 4D CTA and DSA image analysis

All images were independently reviewed by two neuroradiologists (reviewer 1 and 2 with 30 and 3 years of experience in vascular neuroimaging, respectively). The DSA results were used as gold standard. Both the observers were blinded to the results of the cerebral angiography before and after treatment.

With both techniques, DAVF was identified before embolization on the basis of shunt location and identification of feeding artery and drainage vein. The main arterial feeder vessels were defined as branches of the external carotid artery (internal maxillary artery, middle meningeal, ascending pharyngeal, occipital, superficial temporal, and auricular arteries), internal carotid artery (ophthalmic, siphon meningeal, and tentorial arteries), middle cerebral artery, anterior cerebral artery, or vertebrobasilar trunk (posterior cerebral, posterior inferior cerebellar, and posterior meningeal arteries).

After embolization, the cranial vascular conditions, including fistula occlusion and the remnant abnormal vessels, were evaluated by comparison of images with those obtained before embolization separately on both 4D CTA and DSA. If remnant abnormal vessels were found, shunt location was evaluated and the feeding artery and drainage vein were identified as they were before embolization.

2.5. Statistical analysis

Interobserver and intermodality agreement for 4D CTA and DSA were assessed by calculating the κ coefficient using statistical software (SPSS). Quadratic weighted κ statistics with 95% confidence intervals (CIs) were determined using the arbitrary interpretation introduced by Landis and Koch [9], as follows: 0 = poor agreement, 0.00 to 0.20 = slight agreement, 0.21 to 0.40 = fair agreement, 0.41 to 0.60 = moderate agreement, 0.61 to 0.80 = substantial agreement, and 0.80 to 1.00 = almost perfect agreement.

3. Results

4D CTA and DSA were successfully performed in all 11 patients. Fourteen fistulas were identified in the eleven patients on DSA (Table 1). One patient had three fistulas, located in the right sphenoparietal sinus, left cerebral falx, and left tentorium cerebell. In the remaining 10 patients, the DAVF was located in the cavernous sinus (1 was bilateral) in two patients, in the tentorium cerebell in four, the right sigmoid sinus in one, the left occipital in one, the left transverse sinus in one and the cerebral falx in one. For shunt location, interobserver agreement on 4D CTA images was excellent ($\kappa = 1$), as was intermodality agreement with DSA.

The 14 fistulas had 42 feeding arteries, of which 36 (85.71%) were detected on 4D CTA. The interobserver agreement and intermodality agreement for feeding arteries were excellent ($\kappa = 0.828$ and 0.847, respectively) (Fig. 1). Overall, six arteries were missed on the 4D CTA images by both reviewers (Fig. 2): these were the siphon meningeal arteries (in one case), internal maxillary artery (one), posterior meningeal artery (one), ascending pharyngeal artery (two), and ophthalmic artery (one).

With regards to the drainage veins, 4D CTA did not show the drainage veins crossing the intercavernous sinuses for the patient with bilateral DAVF in the cavernous sinus. However, it could clearly display all drainage veins for the other patients, these findings corresponded with those on DSA, and interobserver agreement regarding drainage veins was excellent ($\kappa = 1$).

Seven patients underwent embolization immediately after angiography. The average interval between angiography and