Peri-therapeutic quantitative flow analysis of arteriovenous malformation on digital subtraction angiography

Tzung-Chi Huang[1], Tung-Hsin Wu[2], Chung-Jung Lin[3], Greta S.P. Mok[4], Wan-Yuo Guo[3,*]

[1]Department of Biomedical Imaging and Radiological Science, China Medical University, Taiwan

[2]Department of Biomedical Imaging and Radiological Sciences, National Yang-Ming University, Taiwan

[3] Department of Radiology, Taipei Veterans General Hospital, and National Yang-Ming University, Taiwan

[4]Department of Electrical and Computer Engineer, Faculty of Science and Technology, University of Macau, Macau

*Corresponding author: Wan-Yuo Guo, M.D., Ph.D.

Department of Radiology, Taipei Veterans General Hospital, Taiwan,
201, Shi-Pai Road, Sec. 2, Taipei, Taiwan 11217
Tel: 886-2-28757481
E-mail: wyguo@vghtpe.gov.tw

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Abstract

Background and Purpose: Digital subtraction angiography (DSA) provides detailed hemodynamic information in vascular. However, the imaging interpretation is mainly based on physician's experience and observation. We aim to quantitatively study the peri-therapeutic blood flow changes of a cerebral arteriovenous malformation (AVM) treated by embolization using optical flow estimation on DSA.

Methods: A 37-year-old female patient with an AVM in right frontal lobe of brain was enrolled. Optical flow method with a pixel-by-pixel measurement was applied to determine the blood flows in brain vessels on anterior-posterior and lateral views DSA before and after embolization.

Results: Towards normalization of blood flows as a result of embolization was determined semi-quantitatively on the post-therapeutic DSA.

Conclusions: Optical flow analysis on DSA has illustrated the potential of quantifying intracranial blood flows in patients with cerebral vascular disorders and the therapeutic effects.

Key Words: Arteriovenous malformations, hemodynamics, angiography, flow measurement

Introduction

Digital subtractive angiography (DSA) remains the gold standard for studying intracranial vascular diseases in clinical practice, although other less-invasive imaging tools, e.g. computed tomography (CT), CT angiography (CTA) and MR angiography (MRA) are available and provide acceptable temporal resolution for screening and post-therapeutic following-up [1-2]. The interpretation of hemodynamics on DSA is usually qualitative and based on physicians experience and observation, and an objective and quantitative assessment is still a clinical challenge.

Cerebral arteriovenous malformations (AVM) contain abnormal vascular network, named nidus, through which arterio-venous (AV) shunts occur and as a result, intracranial hemodynamics are disturbed locally or globally. Clinically, the hemodynamics disturbance of AVM may cause hemorrhage, seizures, headache and focal neurological deficits. These clinical manifestations depend on the severity of hemodynamic disturbance and anatomical location of malformations. Endovascular treatment, as one of the common treatments for cerebral AVM, aims to block the AV shunts by intravascularly injecting embolization material into the AVM under the guidance of DSA. With embolization, a normal intracranial hemodynamics is reconstituted and the clinical manifestations are diminished. In this clinical scenario, blood flow analysis would help in strategy-taking of clinical management. In this study, we develop a semi-quantitative assessment technique based on optical flow method (OFM) to evaluate therapeutic effects through DSA.

Materials and Methods

A 37-year-old female patient with an AVM located in right frontal lobe was enrolled. The AVM presented red eye, blurring vision, diplopia. It was treated by embolization by using detachable coils and N-butyl-2-cyanoacrylate (NBCA)/Lipiodol® mixture for the fistula components of AVM. Conventional DSA before and after embolization were acquired. The imaging parameters were: angio-catheters being placed at the C4 vertebral body level for common carotid angiography (70 kVp; 338 mA, 6 frames/second); a total of 12 ml 60% diluted iodinated contrast medium (300 mg iodine/mL) being injected in 1.5 seconds by a power injector; interleaved images being acquired on anterior-posterior (AP) and lateral (LAT) projections.

Two different phases, arterial and venous phase, DSA images for analysis were selected by two neuroradiologists to mitigate observer bias. Each phase contains four to six image frames, in which movement of the iodinated blood in arteries and veins were recorded.

Optical flow method (OFM), a deformable image registration algorithm to register the optical images from different time phases and to provide blood flow measurement on successive images [3-4], was utilized to analyze the DSA images. The changes of imaging density inside blood vessels on two consecutive images and the movement of pixel per second formed the basis of OFM estimation for pixel-by-pixel flow measurements. The study was approved by the institutional review board of the hospital.

Results

Fig. 1 and Fig. 2, respectively, illustrate the color-coded peri-therapeutic OFM measurement of the AVM on AP and LAT views. On AP views (Fig.1), the mean flow of the feeding arteries was 10.22±2.86 pixel/second and was 7.98±1.98 pixel/second, respectively, before and after embolization. The mean flow of the draining veins was 9.61±1.47 pixel/second and 6.17±2.21 pixel/second, respectively, before and after embolization. The decrease of mean blood flow was, respectively, 22% and 36% in arterial and venous phases. On LAT view (Fig. 2), the high flows were mostly shown on feeding arteries at arterial phase (Fig. 2a) and on AVM nidus at venous phase (Fig. 2c) before treatment. The mean flow measurements of the feeding arteries was 17.74± 5.86 pixel/second and was 10.44±6.91 pixel/second, respectively, before and after embolization. The mean flow of the draining veins was 12.87±1.47 pixel/second and 10.47±3.44 pixel/second, respectively, before and after embolization. The decrease of mean blood flow was, respectively, 41% and 19% in arterial and venous phases.

Discussion

Blood flow is inversely proportional to the resistance of vessel [5]. Arteriovenous malformations (AVM) are characterized by a low resistance in intra-nidal vascular structures due to the lack of interposing capillaries [6]. Based on the study results, the decrease of mean blood flow after embolization was 22% and 36% in arterial and venous phases on AP view and was 41% and 19% in arterial and venous phases on lateral view. The flow reduction met the goal of embolization for closing the fistula component of AVM and slowing down the trans-AVM flows. Similar to the previous report, the therapeutic effects of decreasing trans-shunt flows after embolization were well illustrated, in another manner, by the semi-quantitative blood flow measurements using OFM in the current study [7].

Conclusion

We have developed a semi-quantitative blood flow measurement of DSA using OFM. The objective and parametric hemodynamic information of an AVM nidus, and its feeding arteries and draining veins may facilitate the therapeutic decision-making in clinical practice.

Captions

Fig.1. Anterior-posterior views of OFM estimation of blood flow overlaid on DSA images with color code. Red and green colors on (a, c) indicate high flows in feeding arteries, nidus and draining veins of AVM before embolization on arterial (a) and venous (c) phases. After embolization (b, d), the hemodynamics changes toward normalization and less high flow components is illustrated. .

Fig.2. Lateral views of OFM estimation of blood flow overlaid on DSA images with color code. Red and green colors on (a, c) indicate high flows in feeding arteries, nidus and draining veins before embolization on arterial (a) and venous (c) phases. After embolization (b, d), the hemodynamics changes toward normalization and less high flow components is illustrated.

Disclosures

All authors state that they have no conflicts of interest.

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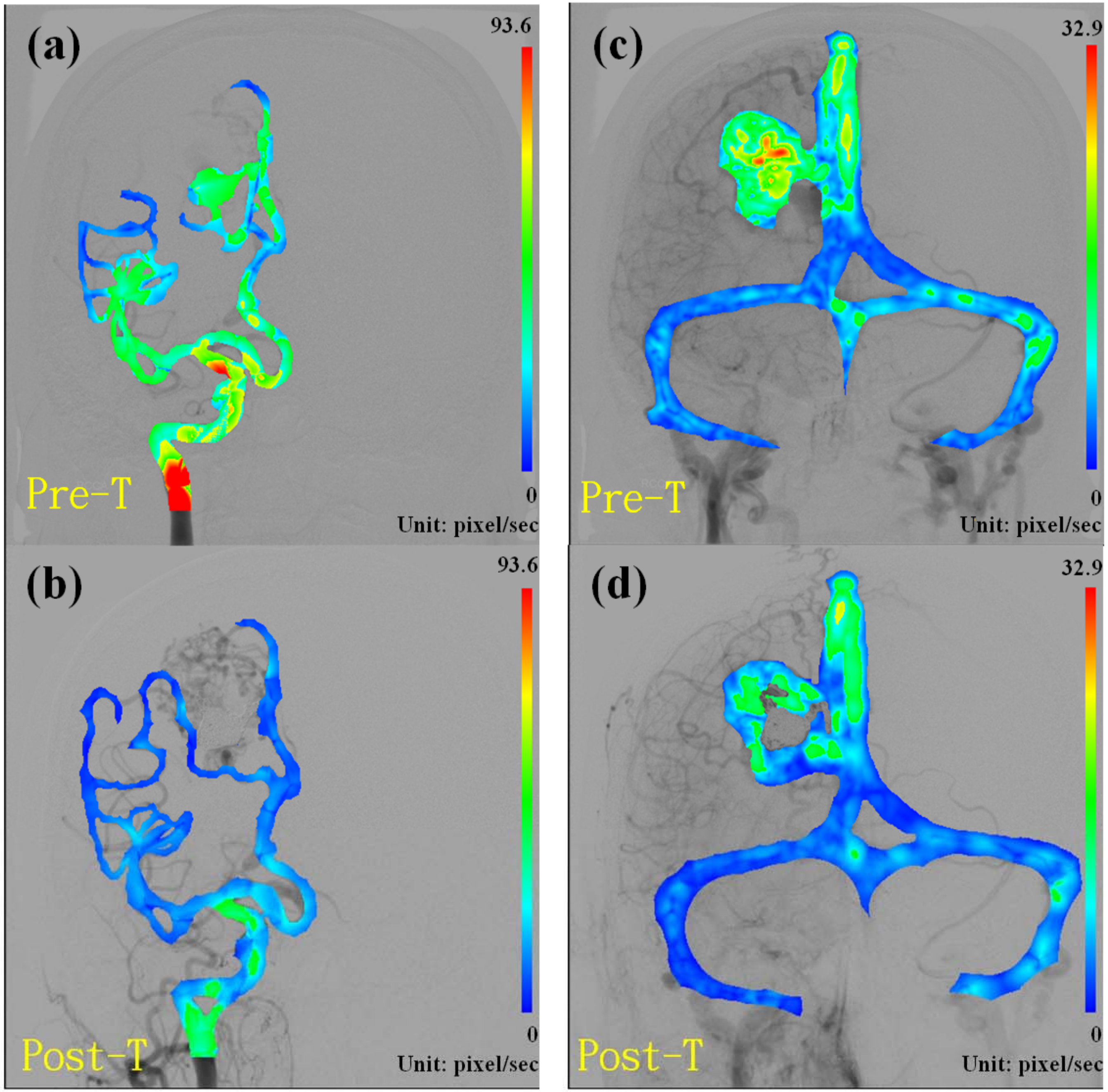
References

1. Schuster L., Schenk E., Giesel F., Hauser T., *etal*. Changes in AVM angio-architecture and hemodynamics after stereotactic radiosurgery assessed by dynamic MRA and phase contrast flow assessments. Eur Radiol (2011) 21:1267–1276
2. Klingebiel R., Siebert E., Diekmann S., Wiener E., Masuhr F. *etal*. 4-D imaging in cerebrovascular disorders by using 320-slice CT. Acad Radiol (2009): 16:123–129

3. Wu CC, Zhang G, Huang TC, Lin KP. Red blood cell velocity measurements of complete capillary in finger nail-fold using optical flow estimation. Microvasc Res (2009):78:319-24.
4. Wu CC, Lin WC, Zhang G, Chang CW, Liu RS, Lin KP, Huang TC. Accuracy evaluation of RBC velocity measurement in nail-fold capillaries. Microvasc Res (2011):81:252-260
5. Nornes H, Grip A. Hemodynamic aspects of cerebral arteriovenous malformations. J Neurosurg (1980): 53:456–464
6. Guo WY, Lee SM, Chang YC, Pan HC. The impact of arteriovenous malformation radiosurgery on the brain: from morphology and perfusion to neurocognition. Stereotact Funct Neurosurg (2006):84:162–169
7. Guo, WY, Wu YT, Wu HM, Chung WY, Kao YH, Yeh TC, Shiau CY, Pan DHC, Hsieh JC. Toward Normal Perfusion after Radiosurgery: Perfusion MR Imaging with Independent Component Analysis on Brain Arteriovenous Malformations. AJNR (2004): 25:1636-1644

Fig. 1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(c)
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Post-T
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(d)
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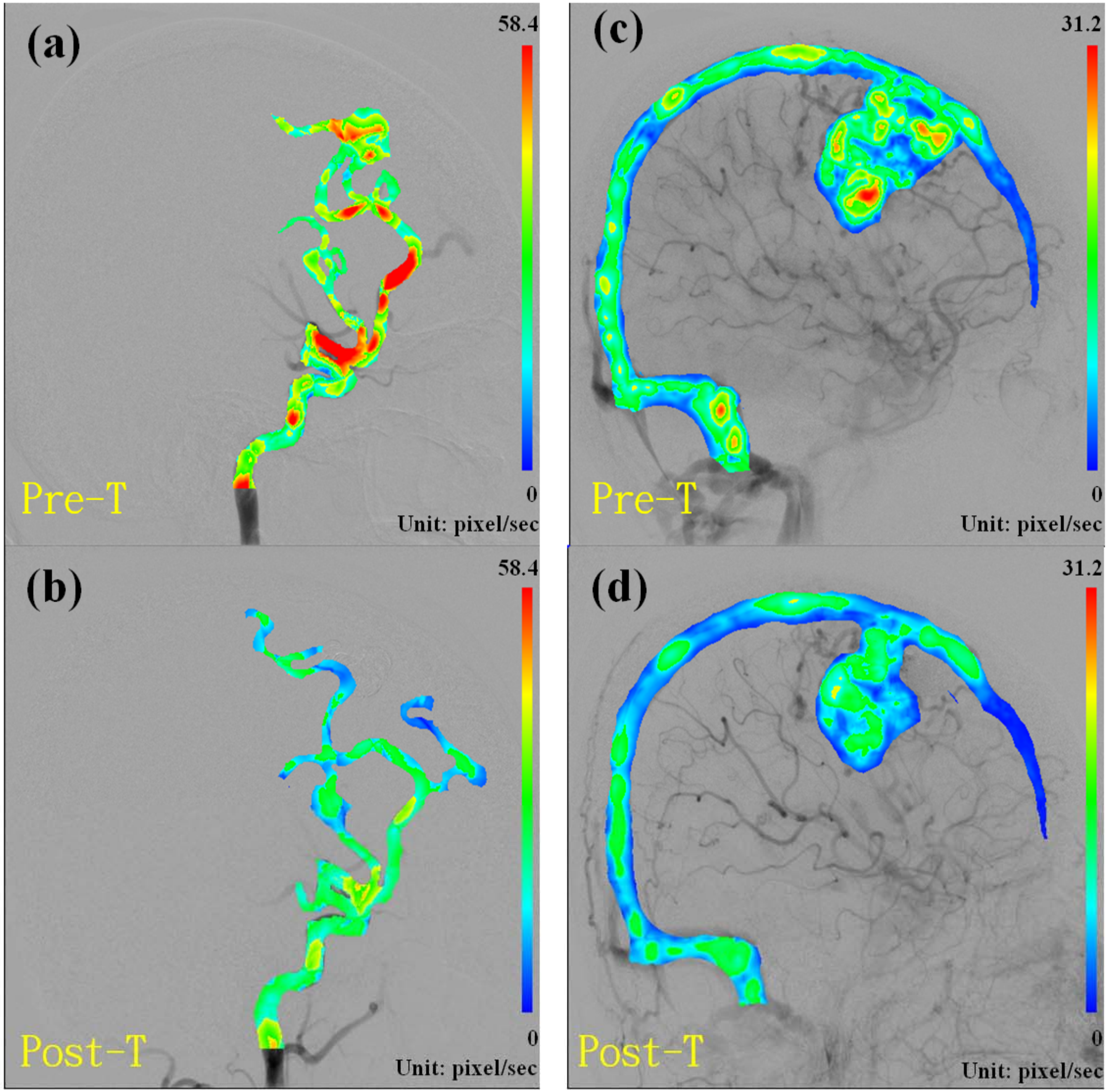
Fig. 2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