Quantitative Assessment of collaterals from External Carotid Artery with Modified Vessel Encoded Arterial Spin Labeling

Yi Dang[1], Bing Wu[2], Ying Sun[3], Dapeng Mo[4], Xiaoying Wang[1,2], Jue Zhang[1,3], and Jing Fang[1,3]

[1]*Academy for Advanced Interdisciplinary Studies, Peking University, Beijing, China, People's Republic of,* [2]*Dept. of Radiology, Peking University First Hospital, Beijing, China, People's Republic of,* [3]*College of Engineering, Peking University, Beijing, China, People's Republic of,* [4]*Dept. of Neurosurgery, Peking University First Hospital, Beijing, China, People's Republic of*

Purpose:

In patients with carotid stenosis or occlusion, cerebral blood could be supplied through collateral pathways to improve regional blood flow and protect against ischemic events [1-2]. In general, the sources of collateral circulation can be divided into two pathways: the principal collateral through the arteries of the circle of Willis; and the secondary pathways consisting of external carotid artery (ECA) via the ophthalmic artery and leptomeningeal vessels. Once the primary circulation fails, the secondary collateral pathways are presumed to be recruited. The contribution of collaterals from internal carotid can be assessed by depicting of vascular perfusion territories using arterial spin labeling [3]. But so far there is no method available to evaluate the collateral perfusion territory from external carotid in MR. In this study, we present a new labeling scheme on the basis of the vessel-encoded arterial spin labeling (VE-ASL) to quantitatively assess perfusion territory of external carotid.

Materials and Methods:

Two patients (1male, 1female, age 46 to 63 years) with carotid stenosis or occlusion, were examined in this study. Carotid stenting was performed on the right internal carotid artery (ICA) of one patient and EC/IC bypass was performed on other patient. The patients were scanned twice: 1 week before surgery and 2 weeks after surgery. The study protocol was approved by the ethics committee, and written informed consent was obtained from all participants.

To encode the contribution of ECA with separation from right ICA, left ICA, and vertebral arteries (VAs), the modified tagging scheme based on the Hadamard matrix is developed here shown on the right [4]:

$$y = Ax$$

$$A = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ -1 & 1 & 0 & 0 & 1 \\ 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & -1 & 1 & 1 \end{bmatrix} \qquad x = \begin{bmatrix} R \\ L \\ V \\ E \\ S \end{bmatrix}$$

where y is the resulting signal intensities; R, L, V, E, and S in x are the contributions of tagged blood signals from the right ICA, left ICA, VAs, ECA and static tissue, respectively, and in the matrix A, ‘1’ ‘-1’ and ‘0’ represent the inflowing blood of specific vessel fully relaxed, fully inverted and saturated, respectively. Thus the first row of the encoding matrix A corresponds to the control state in that all vessels and static tissue are fully relaxed in the labeling plane. The other three rows of A, on the other hand, present the steps to encode the perfusion territories of right ICA, left ICA, VAs and ECA, respectively.

The scanning parameters of the modified VE-ASL were as follows: The tagging pulse-train length was 1600 ms; the post-labeling delay time was set at 1000ms, TR/TE, 3000/3.4 ms; section thickness/section gap, 8/2 mm; FOV, 240 mm; matrix, 128. Seven axial imaging sections were also acquired in the caudal-to-cranial direction. The total scan time was 18.3 minutes: localizer (1 minute), Magnetic Resonance Angiogram (5 minutes), and modified VE-ASL (4.1*3 minutes).

Data were processed using Matlab (Mathworks, Natick, Mass). The perfusion territories including those of the right ICA, left ICA, VAs and ECA were generated by pseudo-inversion of the modified encoding matrix. To quantify CBF, the signal intensity was fitted to the perfusion model described by Wong [5], with the following values as the physical constants24: α (efficiency of the inversion pulse) = 0.7, T_{1blood} = 1664 ms.

Results:

Pre- and postoperative imaging with the modified VE-ASL preformed in the patients reveals the hemodynamic changes as well as the improvement of perfusion, as shown in Figure 1. Being consistent with the Digital Subtraction Angiography (DSA) result (Figure 1A), Figure 1B displays the blood flow from ECA to supply the right hemisphere before surgery. Figure 1C gives the results after carotid stenting, with much less perfusion of ECA (in yellow) in right hemisphere. Before carotid stenting, the right Anterior cerebral artery (ACA) and middle cerebral artery (MCA) territory received 14.3 mL/min/100g blood flow from right ICA and 25.2 mL/min/100g from ECA. The supply of ECA to the right ICA was interpreted as collateral flow compensating for the impairment of right ICA perfusion. Postoperatively, the blood flow of the right hemisphere of brain was apparently higher than that before carotid stenting. The right ICA supply had increased from 14.3 to 42.2 (unit mL/min/100g). Meanwhile, the ECA supply to right ICA territory had decreased from 25.2 to 2.0 (unit mL/min/100g). After surgery, moreover, the blood flow of the right ICA perfusion territory was even higher than that of the left ICA territory, which was consistent with the hyper-perfusion after carotid stenting.

Perfusion territories of a patient with left MCA occlusion undergoing bypass surgery are shown in Figure 2. After the bypass surgery, a blood flow of 11.8 mL/min/100g from ECA was detected to supply the left ICA perfusion territory as collateral flow, in keeping with the DSA result.

Conclusions:

Vascular territories obtained with our proposed approach are consistent with cerebrovascular anatomy and quantitative assessment of external carotid supply in subjects with and without pathology shows to be helpful in therapeutic evaluation.

References:

[1] Liebeskind DS. Stroke. 2003;34:2279-2284.
[2] Yamauchi H, et al. JNNP. 2004; 75:1697-1701.
[3] Wong EC. MRM. 2007;58:1086-1091.
[4] Ying Sun, et al. ISMRM , 2010; #1764.
[5] Wong EC. JMRI. 2005;22:727-731.

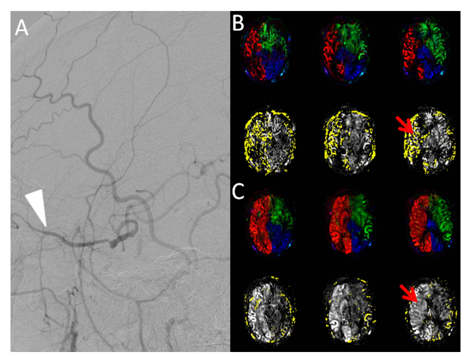

Figure 1. DSA result (left) and vascular territories (right) in a patient undergoing carotid stenting for right ICA stenosis. A, DSA result of the patient before surgery showing there is collateral flow from ECA (white arrow). B, Preoperatively, the collateral supply is manifested as ECA supply to the right ICA territory (red arrow). C, Postoperatively, there is normalization of right ICA perfusion with corresponding reduction of collateral supply (red arrow). Hyper-perfusion of right hemisphere after stenting is also clearly shown.

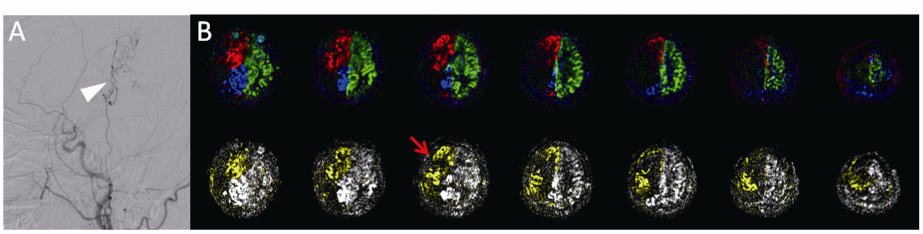

Figure 2. DSA result (A) and vascular territories (B) in a patient with left MCA occlusion after EC/IC bypass surgery. Postoperatively, the blood flow from ECA is detected (red arrow), in agreement with the collaterals shown on DSA (white arrow).