Distinguishing between Anterior Cerebral Artery and Middle Cerebral Artery Perfusion by Color-Coded Perfusion Direction Mapping with Arterial Spin Labeling

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Summary: The purpose of this study was to evaluate collateral circulation by describing anterior cerebral artery and middle cerebral artery perfusion areas. Pairs of image sets were used for each hemisphere: one set with lateral saturation (ie, perfusion by MCA) and orange gradation indicating perfusion from the lateral side (ie, perfusion by ACA); greater intensity of a pixel was greater in image sets with medial saturation, perfusion of the areas with ACA perfusion become 70% MCA stenosis were included in the MCA stenosis group. All participants provided informed consent for the imaging performed in this project.

We used arterial spin labeling to describe the direction of perfusion. For image sampling, a signal intensity targeting with alternating RF-half Fourier single shot turbo spin-echo (STAR-HASTE) sequence (10.9/87.0 [TR/TE]; matrix, 256 × 72; field of view, 300 mm; section thickness, 8 mm) was applied. To determine directions of perfusion by arterial spin labeling, we made two sets of images: a set with saturation pulse on the medial side (medial set) and a set with saturation pulse on the lateral side (lateral set). The inversion time for spin labeling pulse was 800 ms. To reduce noise and obtain sufficient signals, we acquired 30 images for each image set. To compare signal intensity between the two image sets, we performed a t test, rather than simple subtraction. When the signal intensity of a pixel was greater in image sets with medial saturation than in those with lateral saturation, perfusion of the pixel was from the lateral side. A pixel-by-pixel t test was performed for each pair of images. We displayed P values by color code, with blue-colored gradation according to P values indicating perfusion from the lateral side (ie, perfusion by MCA) and orange-colored gradation indicating perfusion from the medial side (ie, perfusion by ACA); greater P values indicated greater perfusion.

To eliminate effects of CSF flow on half Fourier single shot turbo spin-echo images, we deleted the CSF signal intensity by thresholding before the t test. To evaluate distribution of ACA and MCA perfusion areas, we set up three imaging planes, as follows: plane A, sagittal plane, including internal carotid artery top (superior margin of internal carotid artery); plane B, 10-degree laterally tilted sagittal plane, including internal carotid artery top; plane C, 20-degree laterally tilted sagittal plane, including internal carotid artery top (Fig 1). Orange-colored areas within the region outside the lateral ventricle and anterior to the parietooccipital sulcus were considered areas with ACA perfusion. The ratios of areas with ACA perfusion were calculated in the above three planes for each case, and distributions of ACA areas were compared between the two groups.

Results

With the above method, distribution of the area with perfusion from the lateral and medial sides was clearly described on color-coded perfusion direction maps (Figs 2–4). Percentage of area with ACA perfusion is shown in Figure 5. In participants with intact MCAs, mean ratios of areas with ACA perfusion were 80% on plane A, 59% on plane B, and 42% on plane C. Thus, as the imaging plane shifts to the lateral side, the areas with ACA perfusion become...
In participants with MCA stenosis or occlusion, mean ratios of areas with ACA perfusion were 79% on plane A, 68% on plane B, and 57% on plane C. The area with ACA perfusion was larger than that of participants with intact MCAs, especially in the more lateral planes, indicating lateral extension of areas with ACA perfusion.

Discussion

Perfusion of the cerebrum is covered by three artery systems, and borders between these systems are called watershed areas. Watershed areas are not fixed but may move according to dysfunction of a system. The ACA-MCA watershed area is located in the middle frontal gyrus. With hemodynamic changes from occlusion or stenosis of MCA or ACA, the watershed area moves via development of leptomeningeal anastomosis. Information regarding locations of watershed areas or distribution of ACA and MCA perfusion can aid description of collateral circulation in management of ischemic diseases (4–6).

Distribution of cerebral blood flow can be evaluated by radioisotope imaging. Also, bolus tracking MR perfusion imaging can be used to evaluate cerebral hemodynamics. These modalities are relatively noninvasive and widely used in clinical evaluation. However, they can only show overall flow information and cannot provide flow information for discrete arteries such as the ACA, MCA, and posterior cerebral artery. Flow information for specific arteries can be acquired only by conventional angiography, which is an invasive technique. Although MR angiography can provide morphologic information regarding arteries, flow distributions of peripheral regions cannot be evaluated. MR digital subtraction angiography is a new technique for imaging hemodynamics (7), but it does not provide sufficient information regarding peripheral circulation for evaluation of peripheral blood flow in regions such as watershed areas. Although the phase contrast method is a sequence that can provide information on flow direction, it is mainly used for angiography and not suitable for displaying tissue perfusion.

Arterial spin labeling is a method for describing brain perfusion based on MR imaging. In arterial spin labeling, flowing blood is used as a perfusion tracer for RF (STAR) labeling. Signal intensity targeting with alternating RF is a method of arterial spin labeling perfusion MR imaging that has the great advantage of “flow direction dependence,” unlike other perfusion imaging methods.

With the present trial, we attempted to differentiate regions with ACA and MCA perfusion by describing the direction of perfusion: from the medial side or lateral side of the imaging plane, respectively. The most unique aspect of the present imaging method was that it produced several sagittal oblique images arranged in a “fan” shape, with the hub of the fan at the top of the internal carotid artery. With this arrangement, flow from the medial side of the imaging plane is always from the ACA and flow from the lateral side of the plane is always from the MCA.

For sampling, we used the half Fourier single shot turbo spin-echo (HASTE) sequence (8), which is the only ultrafast sequence we can use with saturation pulse on our system. On half Fourier single shot turbo spin-echo images, CSF has a very high signal intensity, and signal intensity changes due to CSF flow are larger than signal intensity differences due to perfusion of brain parenchyma; this can be an obstacle to statistical processing. As described under Methods, we deleted the CSF signal intensity by thresholding before the t test to eliminate effects of CSF flow. However, it is very difficult to delete the CSF signal intensity by using only thresholding, and some CSF flow artifacts remained on the surface of the brain.

In the present study, the percentage of area with
ACA perfusion was greater in the patients with MCA stenosis or occlusion, indicating enlarged ACA territory and lateral shift of watershed due to leptomeningeal anastomosis. The present method may also be useful in evaluation of chronic ischemic changes in situations such as course watching of moya-moya disease, which shows progressive intracranial arterial stenosis and alteration of arterial perfusion area. The method will also be useful in postsurgical evaluation of the superficial temporal artery-MCA bypass.

**Conclusion**

In cases with MCA stenosis or occlusion, extension of the area with ACA perfusion (indicating collateral circulation) was described on color-coded perfusion direction maps. Color-coded perfusion direction mapping is
a noninvasive, useful tool for obtaining information regarding distributions of ACA and MCA perfusion that cannot be obtained by using conventional perfusion MR imaging. This information may aid in the evaluation of collateral circulation for the treatment of stroke.

References