Introduction

Moyamoya disease (MMD) is a chronic cerebrovascular disease characterized by progressive stenosis and end-stage occlusion of terminal internal carotid arteries [1]. While MMD patients commonly experience frequent transient ischemic attacks (TIA), in most cases no infarction/ischemic lesions can be found on T1/T2/diffusion-weighted MR images. In these circumstances, dysfunctions of cerebral hemodynamics might provide unique information for diagnosis, surgery planning and outcome evaluation of MMD patients.

Currently there is no well-established gold standard for evaluating the complex cerebral hemodynamic patterns in MMD. Methods such as positron emission tomography (PET) [2], single photon emission computed tomography (SPECT) [3], computed tomography perfusion [4], and dynamic susceptibility contrast MRI (DSC-MRI) [5] all have the ability to assess cerebral perfusion. However, due to radiation dose and/or the use of contrast agents, these methods are not suitable for studies involving repeated examinations or long term follow-up research studies.

Arterial Spin Labeling (ASL) provides a non-invasive MRI alternative for measuring Cerebral Blood Flow (CBF), and has been applied for the study of a wide range of ischemic cerebrovascular diseases, such as acute ischemic stroke and MMD [6]. Commonly used ASL methods like PICORE Q2TIPS estimate CBF based on a single fixed delay/transit time, thus differences in time delay between the labeling of the feeding arteries and the arrival of labeled blood into brain tissue at different regions (as reflected e.g. by arterial transit time (ATT) or bolus arrival time (BAT)) introduce undesired variability to the measured signal and limit its interpretation in absolute terms. Therefore, by measuring the full inflow curve at multiple different inversion time points, a more accurately quantified CBF and precise timing information of blood flow (BAT map) can be obtained [7, 8].

In the following case studies, multi-delay ASL (MD-ASL) was used to measure CBF and BAT to evaluate the hemodynamic changes characteristic of MMD patients. The calculation of a CBF and BAT map for a multi-TI series is based on the original formulation of Buxton et al. [9] and is applying a voxel-wise fit. We then compared the performance of the technique with standard first-pass contrast-enhanced dynamic perfusion (DSC MRI).

Method

All patients were examined using a 3T MR system (MAGNETOM Skyra, Siemens Healthcare, Erlangen, Germany) with a 20-channel head-neck coil. The MD-ASL images were acquired using a prototype sequence ‘Advanced 3D ASL’ with the following parameters: 3D GRASE imaging with FAIR Q2TIPS labeling, TR 4600 ms, TE 22 ms, slice thickness 4 mm, bolus duration 700 ms, 16 inversion times ranging from 480 to 4080 ms, total acquisition time 5 min including an M0 scan. DSC-MR images were post-processed though standard syngo.via pipeline using local AIF method.

Patient history and imaging findings

In these case studies, patterns of blood perfusion were bilaterally evaluated based on different blood circulation areas as shown in figure 1.

1 Work in progress, the product is currently under development and is not for sale in the US and in other countries. Its future availability cannot be ensured. The product is not yet licensed for sale in Canada, in accordance with Canadian Law. Performance claims have not been reviewed by Health Canada, and are subject to change. Its future availability cannot be guaranteed.
Case 1:
49-year-old male patient, suffered intermittent numbness and weakness of right hand one year ago, accompanied by recurrent headache and dizziness. From the MRA and DSA images, we could identify a bilateral MCA occlusion and abnormal vascularity. The results of DSC-MRI showed long TTP (Fig. 2A) and MTT (Fig. 2C) in the bilateral hemispheric regions supplied by the MCA (M1, M2, M3) as well as in the right posterior circulation cortex (P), whereas CBV (Fig. 2D) was slightly increased and CBF (Fig. 2B) decreased bilaterally in M3. In the MD-ASL results, it can be observed that the topography of long BAT (Fig. 2E) matches TTP map very well, while the area with decreased CBF (Fig. 2F) is similar to DSC-MRI.

Case 2:
49-year-old female patient who suffered of intermittent weakness of the right hand for the past four years. From the TOF-MRA and DSA images, we could see the bilateral MCA and ACA occlusion, as well as abnormal vascular structure. The results of DSC-MRI show long TTP (Fig. 3A) and MTT (Fig. 3C) bilaterally in brain regions supplied by MCA and ACA (A, M1, M2, M3), while CBV (Fig. 3D) and CBF (Fig. 3B) partly decreased. The results of MD-ASL showed an increased BAT (Fig. 3E) matching those observed in TTP and MTT as obtained with DSC-MRI. ASL-CBF images (Fig. 3F) also showed decreased CBF in the same area (bilateral M3) to DSC-MRI.

The upper row shows the results obtained by DSC-MRI: time to peak (TTP) (2A), cerebral blood flow (CBF) (2B), mean transit time (MTT) (2C), cerebral blood volume (CBV) (2D). The lower row shows the MD-ASL results including bolus arrival time (BAT, 2E) and ASL-CBF (2F), as well as brain vascular images collected by MR angiography (TOF-MRA) (2G), and Digital Subtraction Angiography (DSA) (2H).

TTP (3A), CBF (3B), MTT (3C), CBV (3D) obtained by DSC-MRI. BAT (3E), CBF (3F) obtained using MD-ASL. Brain angiographic images obtained with TOF-MRA (3G) and DSA (3H).
Case 3:

48-year-old female patient, suffered continuous weakness and numbness of left arm for the past seven years, and continuous weakness of left leg starting one year ago. From the MRA (Fig. 4G) and DSA (Fig. 4H) images, we could see the stenosis of bilateral MCA, ACA, left PCA and abnormal vascularity. The results of DSC-MRI show long TTP (Fig. 4A) and MTT (Fig. 4C) in areas A, M1, M2, M3, P of the left hemisphere, and areas A, M1, M2, M3 of the right hemisphere, while CBV (Fig. 4D) decreased in bilateral M3 and CBF (Fig. 4B) decreased in bilateral M1 and M3. In MD-ASL images, long BAT (Fig. 4E) areas were matched with the TTP map very well, and CBF (Fig. 4F) decreased in the similar area compared to DSC-MRI.

Conclusion

Our preliminary results demonstrate that the multi-delay 3D ASL method is able to robustly deliver both the arterial transition time and cerebral blood flow. By incorporating BAT information during the blood flow calculation, multi-delay ASL is capable of providing more accurate and less biased CBF, showing an equivalent performance to DSC-MRI in patients with Moyamoya disease. Because ASL is a non-invasive technique, there is high potential in using it to frequently monitor cerebrovascular diseases over long periods, or as a contrast-free quantitative measure of CBF in longitudinal studies.

References


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