Brain Perfusion Imaging in a Case of Thalamic Stroke: a Clinical Application of 3D Pseudo-Continuous ASL (PCASL)

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Abstract

Brain perfusion MRI can help us better understand and monitor the metabolic and functional correlates of a stroke lesion, both in the acute and chronic phase and beyond the local tissue damage. Arterial spin labeling (ASL) allows repeated perfusion measurements and quantifications of cerebral blood flow (CBF) over the whole brain without the need for exogenous contrast. When it comes to monitoring stroke patients, ASL can therefore provide useful information about the short-term (dynamic) or long-term (e.g., chronic vs. acute) effects of pharmacological treatments or surgical interventions with respect to stroke onset.

Here we report a case of thalamic stroke where the relationship between the whole-brain CBF pattern and the tissue outcome is illustrated in the subacute and chronic phases, before and after five months of pharmacological treatment, by co-registering CBF maps from 3D pseudo-continuous ASL (3D PCASL)[1] images and T2-weighted fluid-attenuated inversion recovery

[1]*WIP, the product is currently under development and is not for sale in the US and in other countries. Its future availability cannot be ensured.*

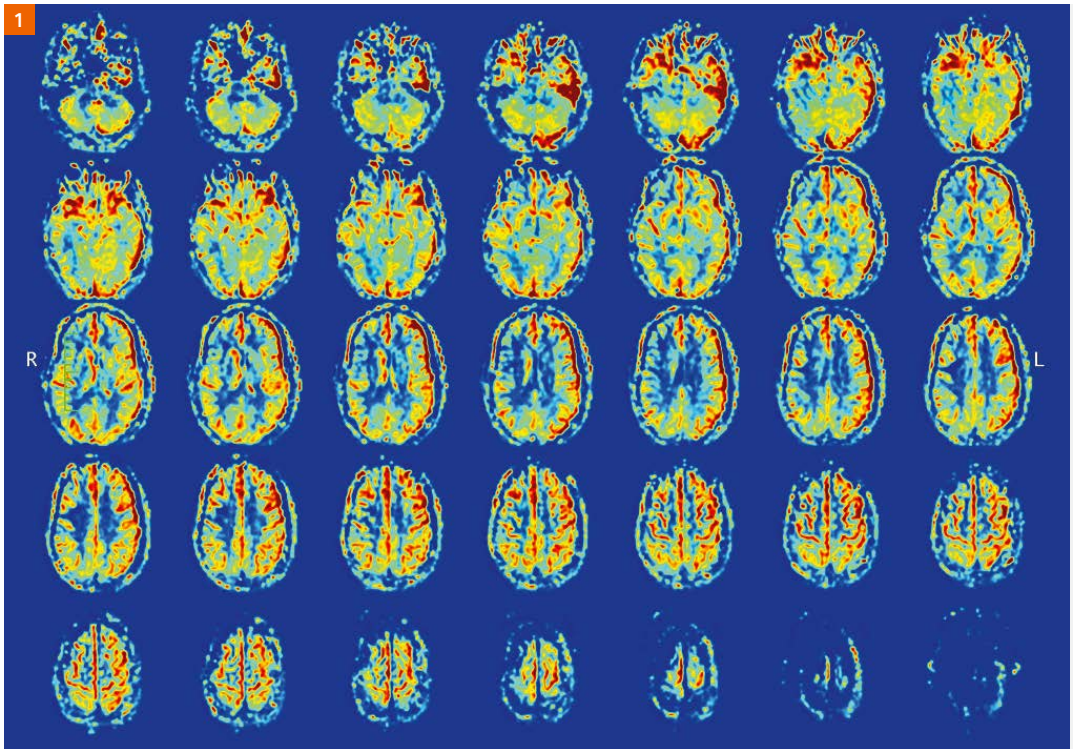

Figure 1: rCBF map (mL / 100 g / min) of a 31-year-old woman with a stenosis of the distal basilar artery, acquired in the subacute phase using 3D PCASL. The color map "jet" (blue/green: low perfusion, yellow/red: high perfusion) was used to map the image values.

(3D FLAIR) images. We compare these to conventional magnetic resonance angiography (MRA) images.

Visualizing changes in perfusion patterns provided significant information that could not be easily produced with conventional non-invasive MRI techniques, and might therefore provide new insight into the functional, vascular, and neuronal changes that follow an ischemic brain injury. If introduced to a routine clinical setting, 3D PCASL could certainly allow the non-invasive and rapid collation of quantitative parameters that might be useful predictors of outcome. It could also provide a deeper understanding of metabolic and vascular phenomena caused by cerebro-afferent vessel occlusion, and therefore help improve tailored approaches to ischemic stroke.

Introduction

Monitoring brain perfusion helps us to understand the metabolic and functional correlates of both acute and chronic cerebrovascular lesions in a way that goes beyond the local tissue damage associated with the structural lesion. Compared to dynamic susceptibility contrast (DSC), arterial spin labeling (ASL) allows repeat perfusion measurements within a few hours and over weeks or months. It also provides absolute quantifications of cerebral blood flow (CBF) across the entire brain without the need for exogenous contrast [1]. When it comes to managing patients with acute stroke, ASL can therefore provide useful information about the short-term (dynamic) or long-term (e.g., chronic vs acute) effects of pharmaco-logical treatments or surgical interventions [2]. Among the different ASL implementations on clinical MRI scanners, pseudo-continuous 3D ASL[1] is recommended by the ISMRM Perfusion Study Group as the method of choice for clinical imaging [3].

Here we report on a patient with vertebrobasilar stroke caused by spontaneous basilar artery vasospasm. We illustrate the relationship between the whole-brain CBF pattern and the narrowing of the intracranial artery in the subacute phase, and show the tissue outcome and the consequences of ischemia in strategic brain regions (hippocampus and thalamus) after five months of pharmacological treatment. In particular, we postprocessed ASL images obtained with a prototype version of the 3D pseudo-continuous ASL (3D PCASL) sequence. CBF maps from 3D PCASL images were coregistered between two MRI studies and with T2-weighted fluid-attenuated inversion recovery (3D FLAIR) images. Conventional magnetic resonance angiography (MRA) was performed with 3D time-of-flight (3D TOF), and maximum intensity projection (MIP) views were obtained.

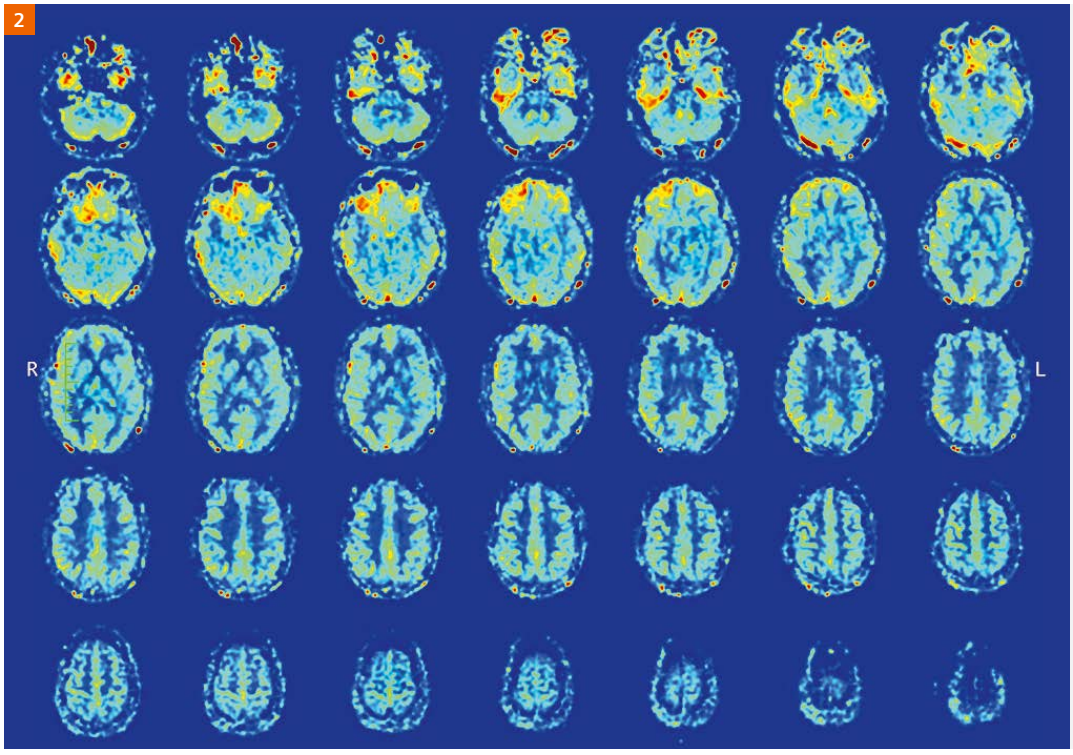

Figure 2: rCBF map (mL / 100 g / min) of a 31-year-old woman, acquired in the chronic phase using 3D PCASL five months from stroke onset when the basilar artery appeared normalized. The color map "jet" (blue/green: low perfusion, yellow/red: high perfusion) was used to map the image values.

Case report

In September 2017, a 31-year-old woman presented with a sudden severe headache, confusion, and amnesia that had developed after physical exertion. Conventional MRA showed an acute posterior circulation stroke involving the hippocampal formation and the anterior thalamus on the right side in particular. It also showed a stenosis of the distal basilar artery consistent with vasospasm. The patient was treated with nimodipine, which stopped the headache and rapidly improved her cognitive performance. Basilar artery lumen slowly normalized in the subsequent month.

Both during the subacute phase and five months later, besides MRA, we also assessed tissue lesions and brain perfusion with, respectively, 3D FLAIR and 3D PCASL sequences on a 3T MR scanner (MAGNETOM Skyra, Siemens Healthcare, Erlangen, Germany) equipped with a 20-channel head-neck coil. MRA images were obtained from 3D time-of-flight (3D TOF) images using the maximum intensity projection (MIP) in the Siemens Healthcare *syngo* software. The 3D FLAIR sequence was set up with the following parameters: Repetition/echo time (TR/TE): 5000/387 ms; inversion time (TI): 1800; slice thickness: 1 mm; matrix: 384 x 384; field of view (FOV): 229 x 229 mm2. The 3D PCASL sequence employs the 3D GRASE readout module and uses a pseudo-continuous labeling scheme with optional background suppression as described in [4–6]. It was set up with the following parameters: TR/TE: 4600/15.6 ms; FOV: 192 x 192 mm^2; slice thickness: 3 mm; labeling duration: 1500 ms; post-labeling delay: 1500 ms; M0 prescan. Total scan time including M0 was 5:27 min:sec (1 M0 image, 6 control/label image pairs). A rCBF map was also calculated from the prescan M0 and the label-control series using the formula in [3] and provided by the inline scanner software. 3D T1-weighted MPRAGE images were acquired as anatomical references to improve coregistration between series and exams (time points). The 3D T1 MPRAGE sequence used the following parameters: TR/TE: 5000/387 ms; TI: 1800; slice thickness: 1 mm; matrix: 256 x 256; FOV: 256 x 256 mm^2.

To facilitate a visual comparison of the results across the two time points, FLAIR and PCASL images were first registered to their corresponding MPRAGE images (acquired at the same time point) and then jointly registered to the common anterior-posterior commissure (ACPC) plane, as determined on the MPRAGE images, using affine transformations. Thereby, the FLAIR images and CBF maps from the two time points could be displayed using exactly the same transversal slice, which was selected on the FLAIR images to bisect a bilateral thalamic lesion that appeared as two hyperintense spots. The rCBF maps were obtained from perfusion-weighted maps using the M0 prescan and parameters in [7]. In addition, for display purposes, the same maps were also normalized to the maximum rCBF value (map peak).

Figures 1 and 2 show the rCBF maps provided from the inline scanner software from the 3D PCASL series acquired respectively in the subacute phase and after five months. The color maps were identically scaled using the same window.

Figure 3 shows the MRA and the 3D FLAIR/PCASL results after postprocessing (coregistration to the common ACPC plane, calculation of the rCBF values, and normalization to the maximum). For the MRA study, the coronal MIP views from the 3D TOF data show the stenosis of the distal basilar artery in the subacute phase (3A) and its normali-zation after five months (3E). The 3D FLAIR images and CBF maps are also shown in the subacute phase (3B, C) and after five months (3F, G). The FLAIR images show a bilateral thalamic lesion as two symmetrical hyperintense spots, which remained substantially unchanged between the subacute (3B) and chronic (3F) phases. The rCBF map in the subacute phase (3C) shows a serpiginous, high absolute CBF surrounding the lesion in the right thalamus, but not in the left. The CBF map normalized to the maximum rCBF value (3D) emphasizes this effect and further highlights inhomogeneous perfusion throughout the gray matter, with relatively low perfusion in the posterior circulation territories and in the right hemisphere. After five months, the rCBF map (3G) shows globally reduced levels of perfusion. However, the normalized CBF map (3H) in particular shows a more homogeneous perfusion pattern throughout the gray matter.

This case illustrates how 3D PCASL CBF measurements can potentially add value beyond the conventional MRA findings. In fact, although MRA allows (in this case) to locate the stenosis, the CBF map provides a richer pattern of the stroke effects, even beyond the territory supplied by the narrowed artery. Specifically, the CBF map in the subacute phase seems to indicate the possible presence (and the distant metabolic consequences) of collateral circulation induced by the hemodynamic adaptation to the stroke event. In fact, when the arterial arrival time exceeds the post-labeling delay (the time required for spins to travel from the labeling plane to the imaged slice), labeled spins become visible as bright intra-arterial high signals. This effect is known as “arterial transit artefact” (ATA) [8] to emphasize that the signal

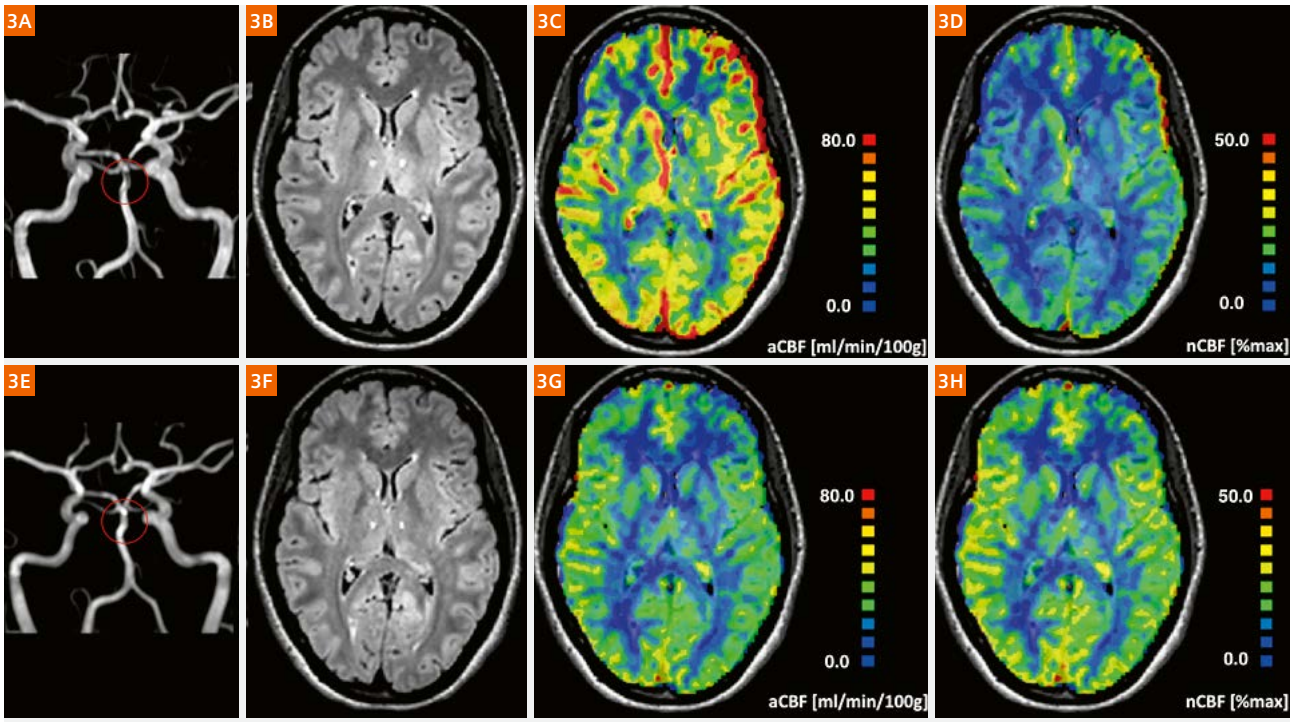

Figure 3:
MRA-FLAIR-ASL study re-elaboration (coregistration to common ACPC plane, CBF normalization): **(3A)** A 31-year-old woman with a stenosis of the distal basilar artery on MRA (coronal MIP from 3D TOF images); **(3B)** the FLAIR image in the subacute phase shows bilateral thalamic lesions; **(3C)** 3D PCASL shows a serpiginous, high absolute CBF close to the lesion in the right thalamus, but not in the left; **(3D)** normalized CBF shows inhomogeneous perfusion throughout the gray matter, and relatively low perfusion in the posterior circulation territories and the right hemisphere; **(3E)** after five months, the basilar artery has normalized on MRA (coronal MIP from 3D TOF images); **(3F)** the thalamic lesions did not change substantially on the FLAIR image; **(3G)** absolute CBF from 3D PCASL images shows globally reduced perfusion; **(3H)** normalized CBF shows more homogeneous perfusion throughout the gray matter.

comes not from the parenchyma but from the vessel (an unwanted effect under physiological conditions). Such intravascular signals can be attributed to the slow-flowing (stagnant) blood upstream of the occlusion site, and it has repeatedly been shown [9] that detecting stagnant flow using a PCASL sequence can fruitfully complement MRA in localizing occlusions in acute stroke. This notion was substantially supported by our case, where the ATA disappeared during the chronic phase once the artery lumen was normalized. In previous studies, the presence of ATA has also been correlated with an improved outcome (lack of progression to infarct and better clinical outcome) after acute stroke [10]. It could, therefore, indicate the presence of compensating collat-eral flow, which would be a useful prognostic marker. Alternatively, regional increases in CBF values might indicate a "luxury perfusion", which is a maximal arteriolar vasodilation caused by loss of autoregulatory mechanisms in the tissue damaged by recent ischemia [11]. Luxury perfusion is also associated with an improved outcome for the ischemic penumbra.

Of particular interest is the detection of CBF changes in regions far beyond the territory supplied by the affected artery. In this case, CBF probably indicates functional phenomena due to the involvement of strategic brain regions (such as the thalami and the hippocampal formations) that might result in cerebral diaschisis with metabolic suppression far away from the ischemic territory.

Overall, 3D PCASL can provide significant information that cannot be easily produced with other noninvasive techniques, and might provide new insight into the functional, vascular, and neuronal changes that often coexist with an ischemic brain accident.

These techniques, when used in a routine clinical setting, will make it possible to noninvasively and rapidly collate quantitative parameters that could be useful predictors of outcome and provide a more in-depth understanding of metabolic and vascular phenomena caused by a cerebro-afferent vessel occlusion. Ultimately, this could improve tailored approaches to treating ischemic stroke.

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