Arterial Spin-Labeling Magnetic Resonance Perfusion Imaging with Dual Postlabeling Delay in Internal Carotid Artery Steno-occlusion: Validation with Digital Subtraction Angiography

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Background: Arterial spin-labeling magnetic resonance perfusion imaging (ASL-MRI) allows noninvasive measurement of cerebral blood flow (CBF) but depends on the arterial transit time (ATT). With the commonly used single postlabeling delay (PLD) of 1.5 seconds, slow flow through collateral vessels may be underestimated. We used both 1.5 and 2.5 seconds to overcome this problem. We validated these PLD settings by measuring the ATT and identifying the angiographic circulation using digital subtraction angiography (DSA). *Methods:* We retrospectively selected 5 patients with unilateral occlusion or stenosis of the internal carotid artery (ICA) in whom ASL-MRI showed low CBF with 1.5-second PLD in the target area and improved CBF with 2.5-second PLD. We then compared the ASL-MRI findings visually with DSA findings at 1.5 and 2.5 seconds after injection of the contrast. When arterial transit artifacts (ATAs), attributed to stagnant intravascular spin-labeled blood, were observed, DSA findings were analyzed visually at 4.5 seconds. *Results:* DSA revealed that the hypovascular area seen at 1.5 seconds was improved via the primary and secondary collaterals and delayed anterograde flow at 2.5 seconds. Serpiginous or round-shaped ATAs, which appeared in nearly the same configuration on dual PLD ASL-MRI, were attributed to stagnant collaterals and flow in the M2 portion of the middle cerebral artery and ICA during the late venous phase. *Conclusions:* Use of dual PLD times was validated by the DSA findings. ATA detection using the dual PLDs also differentiated well-developed and stagnant collateral vessels from focal hyperperfusion. **Key Words:** Arterial spin labeling—perfusion image—postlabeling delay—digital subtraction angiography.

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Introduction

Arterial spin-labeling magnetic resonance perfusion imaging (ASL-MRI) helps visualize cerebral perfusion and permits assessment of cerebral blood flow (CBF) with the use of magnetically labeled protons in arterial blood as an endogenous tracer.[1-6] ASL-MRI requires no exogenously administered tracer. Thus, both in terms of the physical burden for patients and no additional medical equipment, it is an advanced repeatable perfusion tool compared with conventional computed tomography and magnetic resonance perfusion images, positron emission tomography, and single-photon emission computed

tomography (SPECT), all of which require bolus injections of a contrast medium or radioactive tracer.[1-6]

ASL-MRI has some drawbacks, however. It has a time delay, called the postlabeling delay (PLD), between inversion of blood spins passing through the labeling plane in the neck and collection of images in any planes in the head after labeled blood flows into brain tissue.[1-6] ASL is highly susceptible to the arrival time of labeled blood in tissue, namely, the arterial transit time (ATT).[1-6] The fundamental trade-off of acquiring ASL-MRI images is that a short PLD does not allow complete delivery of the labeled blood to the tissue, and a long PLD results in strong T1 decay and therefore a reduced signal-to-noise ratio.[1] Recent clinical ASL-MRI studies have generally used a PLD of 1.5-2.0 seconds as a trade-off between allowing sufficient delay for visualizing tissue perfusion and maintaining adequate diagnostic quality.[1,7,8]

Cerebral stenotic or occlusive diseases, however, are generally accompanied by a significant reduction in flow velocity because of arterial stenosis or occlusion and the formation of collateral blood flow. These conditions cause prolonged ATT. When using a single conventional PLD, tagged arterial blood does not fully reach the observed planes, and hypoperfusion is found in the target areas,[1,7,8] which can lead to underestimation of the CBF.[1,9] Furthermore, in patients with well-developed collaterals, a single conventional PLD shows apparent hyperperfusion in the territories where collateral blood is stagnant, a condition termed an arterial transit artifact (ATA).[1-6] Consequently, the PLD is the most significant parameter that contributes to accurate assessment of CBF in patients with a stenotic or occlusive disease. Clinical studies have been performed using multiple PLDs with ATT correction to improve CBF quantification.[8-11] At this stage, however, they have not offered absolutely accurate perfusion quantifications and are difficult to apply to routine clinical practice.

Recently, we developed a simple ASL technique using 2 PLD settings. In addition to the routinely used PLD of 1.5 seconds, we selected another PLD of 2.5 seconds to assess the slowly streaming collateral pathway that maintains the cerebrovascular reserve.[7] Lyu et al[12] also reported the usefulness of a dual-PLD method for estimating anterograde and collateral flow in patients with unilateral middle cerebral artery (MCA) stenosis. In a previous report,[7] we validated the setting of the dual PLDs of 1.5 and 2.5 seconds by measuring the ATT and identifying the angiographic circulation, including the collateral network, in the target area using digital subtraction angiography (DSA) as a gold standard,[13] but only in a single case of unilateral occlusion of the internal carotid artery (ICA). Since then, however, we have studied an additional 4 cases with unilateral occlusion or stenosis of the ICA to validate our dual-PLD method. We report all 5 cases here.

Patients and Methods

We retrospectively selected 5 patients with unilateral occlusion or stenosis of the ICA who underwent both routine ASL-MRI with dual PLD and DSA for clinical purposes from January to December of 2014 in Kyushu Rosai Hospital. All patients were men aged 47-79 years (mean 62.2 years). In all 5 patients, ASL-MRI with dual PLD demonstrated low CBF with a PLD of 1.5 seconds in the target area—mostly in the MCA territory—and improved CBF with a PLD of 2.5 seconds. Unilateral occlusion and stenosis of the ICA was found in 2 and 3 cases, respectively. The time interval between the ASL-MRI and DSA examinations was within 5 days.

ASL-MRI was performed using a 3-T scanner (HDxt Signa; GE Healthcare, Milwaukee, WI) equipped with an 8-channel receive-only head coil for signal reception. The arterial spin-labeling (ASL) was prepared using a 3-dimensional spiral fast-spin echo sequence with background suppression for perfusion imaging covering the entire brain, as previously described.[7,14,15] A pulsed continuous protocol was employed. The labeling plane at the neck was perpendicular to the ICA and vertebral artery (VA) located around the foramen magnum. Other acquisition parameters were as follows: 4 arms with 1004 points in each spiral arm, phase encoding in the z direction = 32, section thickness = 4 mm, time to repeat (TR) = 4728, and number of excitation (NEX) = 3. The labeling duration was 1.5 seconds. Two PLDs of 1.5 seconds (1.525 seconds) and 2.5 seconds (2.525 seconds) were chosen, as described elsewhere.[7] Acquisition times (minutes : seconds) of ASL with PLDs of 1.5 and 2.5 seconds were 2:22 and 2:43, respectively.

Acetazolamide loading ^{123}I-iodoamphetamine single-photon emission computed tomography (IMP-SPECT) was performed in case 2, as described before.[7] Cases 1 and 5 with acute infarction underwent IMP-SPECT examination without acetazolamide loading. In cases 3 and 4, data of IMP-SPECT were not available in this report, because the time interval with the ASL-MRI and DSA examinations was over 3 months.

DSA was performed on a flat-panel system (Infinix Celeve-i INFX-8000V; Toshiba, Tokyo, Japan) using a femoral artery approach. Images of the bilateral ICAs and at least a VA injection were acquired and stored. The catheter (4 Fr, JB2; Medikit, Tokyo, Japan) tip was positioned in the cervical portion of the ICA and VA during carotid angiography (CAG) and vertebral angiography (VAG), respectively. In case 5, a patient with severe stenosis of the ICA at the cervical bifurcation, the catheter tip was positioned in the common carotid artery (CCA). A contrast medium of 8-10 mL (iopamidol 370 mg/dL; Bystage; Teva Pharma Japan, Nagoya, Japan) was injected at a flow rate of 5 mL/s. DSA images were obtained at a set rate of 3 frames per second in the lateral, anteroposterior, and/or Town views.