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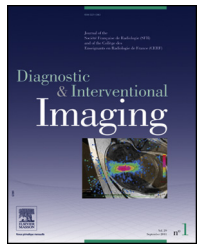

REVIEW /*Neuroradiology*

Arterial spin labeling in clinical pediatric imaging

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Abstract Arterial spin labeling (ASL) perfusion-weighted magnetic resonance imaging is the only approach that enables direct and non-invasive quantitative measurement of cerebral blood flow in the brain regions without administration of contrast material and without radiation. ASL is thus a promising perfusion imaging method for assessing cerebral blood flow in the pediatric population. Concerning newborns, there are current limitations because of their smaller brain size and lower brain perfusion. This article reviews and illustrates the use of ASL in pediatric clinical practice and discusses emerging cerebral perfusion imaging applications for children due to the highly convenient implementation of the ASL sequence.

Many approaches exist to measure brain perfusion such as positron emission tomography (PET), dynamic susceptibility contrast magnetic resonance imaging (DSC MRI) and computed tomography perfusion (CTP). However, these techniques require administration of contrast material and/or exposure to ionizing radiation. Non-invasive and non-radiating

Abbreviations: AIS, Arterial ischemic stroke; ASL, Arterial spin labeling; CASL, continuous ASL; PASL, pulsed ASL; pCASL, pseudo-continuous ASL; ATT, Arterial transit time; AVM, Arteriovenous malformation; CBF, Cerebral blood flow; CTP, Computed tomography perfusion; DSC, Dynamic susceptibility contrast; DWI, Diffusion-weighted imaging; MRI, Magnetic resonance imaging; PC MRI, Phase contrast MRI; PET, Positron emission tomography; PLD, Post labeling delay; PRES, Posterior reversible encephalopathy syndrome; SNR, Signal-to-noise ratio; T1b, Relaxation time constant of arterial blood.

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methods such as Doppler ultrasonography and phase-contrast MRI (PC MRI) do not provide regional brain perfusion measurements, but only an overview based on cervical arterial flow. The emergence of arterial spin labeling (ASL) as a technique that provides both non-invasive and regional cerebral blood flow quantification offers new opportunities for assessing brain perfusion in neonates and children. ASL is currently moving from the field of research into that of routine clinical practice. A few studies have been conducted in pediatric patients and new clinical applications are emerging. These all make ASL a promising perfusion imaging method for assessing cerebral blood flow (CBF) in children [1].

The purpose of this article was to review and illustrate the use of ASL in pediatric clinical practice.

Technical principles

ASL is a non-invasive technique that uses endogenous blood water as a freely diffusible tracer. A previous article in this journal presents the principles of the technique [2]. The protons in arterial blood are magnetically labeled with a radiofrequency inversion pulse applied below the imaging slice in the neck vessels. Several labeling methods exist including continuous ASL (CASL), pulsed ASL (PASL) and pseudo-continuous ASL (pCASL). In CASL, a long flow-induced inversion pulse is applied. In PASL a short inversion pulse is applied to a larger region of the neck. pCASL is a hybrid method that utilizes a train of short RF pulses to mimic the effect of CASL. Because of several benefits the use of pCASL labeling is now recommended [3].

A labeled image is acquired after a minimum transit time for the labeled spins to reach the imaging slice, known as the inversion time or post labeling delay (PLD) (Fig. 1). A control image is acquired without prior labeling. Subtraction of the two images generates a perfusion-weighted image. Because the signal difference is only 0.5—1.5% of the full signal, multiple repetitions are needed to improve the signal-to-noise ratio (SNR). Subsequently, in order to obtain a quantitative perfusion map a quantitative model is required to calculate the ratio between the perfusion-weighted image signal and CBF. A number of parameters influence CBF quantification such as labeling efficiency, longitudinal magnetization of arterial blood, arterial blood and tissue relaxation time constant (T1b and T1t), arterial transit time (ATT), and blood-tissue partition coefficient. These parameters can be assumed or measured and may differ from adult literature values.

Initially proposed in 1996, CBF quantification using the ASL method has been improved with the addition of multiple parameters [4]. This method now has several research and clinical applications in adults [5,6]. However, a number of studies have demonstrated the challenges of optimizing ASL acquisition for subjects across a wide range of vascular and perfusion characteristics [3].

Given the non-invasiveness of the technique, which involves neither venous cannulation nor radiation, it is particularly suitable for children. In addition, ASL offers within-session repeatability and achieves absolute quantification of CBF.

The main drawback of the ASL method is a low SNR. However, there is a physiological improvement in SNR in children compared to healthy adults, mainly due to a higher

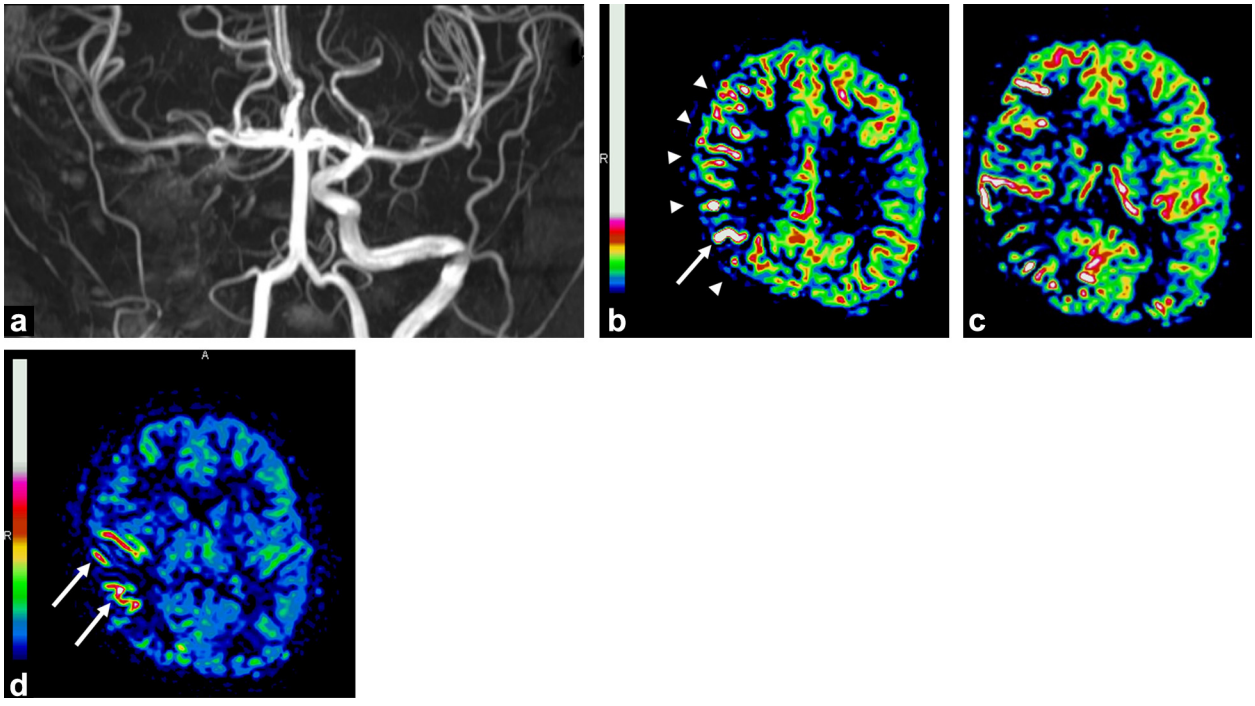

Figure 1. 11-year-old boy with recent surgical right internal carotid occlusion. MR angiogram shows right internal carotid occlusion (a). DWI shows no evidence of ischemia. ASL maps (b—d) show the transit time effect with pseudohypoperfusion of the right hemisphere (arrowheads) as well as linear high signal intensity representing slow flow in cortical vessels (arrows).