From the macro- to the microvasculature : temporal and spatial visualization using arterial spin labeling

Suzuki, Y.

Citation

Suzuki, Y. (2018, November 1). *From the macro- to the microvasculature : temporal and spatial visualization using arterial spin labeling*. Retrieved from https://hdl.handle.net/1887/66665

Author: Suzuki, Y.
Title: From the macro- to the microvasculature : temporal and spatial visualization using arterial spin labeling
Issue Date: 2018-11-01

Chapter 7

Summary and general discussion

In this doctoral thesis, several new techniques for dynamic MR angiography (4D-MRA) and perfusion imaging were developed based on different Arterial Spin Labeling (ASL) techniques, which include pulsed ASL (PASL), pseudo-continuous ASL (pCASL), vessel-encoded (ve) pCASL, time-encoded (te) pCASL as well as simultaneous multi-slice (SMS) pCASL. The underlying motivation of these developments is to reduce the burden on patients by employing non-invasive ASL techniques as potential alternatives to X-ray digital subtraction angiography, contrast-enhanced MRA and perfusion imaging. In each study, the optimum ASL technique was carefully chosen by considering the pros and cons of the technique to achieve better clinical usability, while improving robustness against potential artifacts.

In chapter 2, a novel accelerated time-resolved ASL-MRA technique, ACTRESS, was presented by using PASL. In the ACTRESS approach, a single control image is acquired before the labeling pulse in a Look-Locker multi-delay readout, and this single phase control image is subtracted from the other labeled images acquired with the multi-delay readout. It means that only a single Look-Locker readout is required for the acquisition of both labeled and control images, instead of separate pair-wise acquisitions, thereby reducing the scan time by close to a factor of two as compared to the conventional ASL-based 4D-MRA. To achieve similar image quality to conventional 4D-MRA, optimization of the labeling pulse was carefully performed. Qualitative assessment demonstrated that ACTRESS-MRA could generate 4D-MRA with similar image quality to conventional ASL-based 4D-MRA.

In chapter 3, ve-pCASL was employed to achieve vessel-selective 4D-MRA. It was determined how changes in the gradient settings for pCASL labeling influence the spatial modulation of the inversion profile, and optimizations were performed to achieve a narrower labeling condition, a broader and flatter control condition and a sharper transition between the two conditions. The optimized settings enabled 4D-MRA acquisition by using four Hadamard encodings, instead of eight Hadamard encodings previously proposed in the literature, which means half the scan time compared to this previous study. It was also shown that the use of these new settings lowered the risk of partial labeling of untargeted arteries.

Additionally, in chapter 4, we have presented a combination of vessel-selective pCASL and ACTRESS. By employing pCASL for vessel-selective labeling, instead of PASL as used in the original ACTRESS approach proposed in chapter 2, signal elevation of the static tissue resulting from the intersection of the labeling slab and the imaging volume could be avoided. Moreover, separate visualization of the internal and external carotid arteries could be achieved, which is difficult for PASL because a PASL labeling slab with its large coverage will also label arterial blood in the common carotid artery that feeds both the internal and external carotid arteries. Application of a pre-saturation pulse and the use of optimized parameter settings minimized the static tissue signal fluctuations over the Look-Locker readout, which is essential to avoid elevated background signal that could hinder the visualization of small arteries. This approach allowed vessel-specific visualization of 4D-MRA with very short scan time of 2 – 3 minutes, which will improve the clinical usability dramatically.

In chapter 5, simultaneous acquisition of perfusion and 4D-MRA was proposed by using te-pCASL, in which an optimized labeling duration of each subbolus provided sufficient labeling duration and PLD for perfusion imaging, as well as sufficient temporal resolution to depict the early arterial phase in 4D-MRA. Moreover, reduction of the saturation effects caused by the MRA readout on the perfusion image was achieved not only by using te-pCASL instead of the conventional Look-Locker readout, but also by using relatively low excitation flip angles and a segmented EPI readout inserted after each excitation pulse. These advanced sequence designs allowed the additional acquisition of 4D-MRA within a typical pCASL perfusion imaging scan time, while maintaining sufficient image quality of the perfusion CBF maps.

In chapter 6, an important pitfall of ASL perfusion imaging when combined with SMS and background suppression (BGS) was reported, in which severe subtraction errors can occur when through-plane motion is corrected by traditional motion correction procedures. A new framework was proposed to correct such subtraction errors, which results in improved accuracy of CBF estimation while still allowing the use of conventional motion correction approaches as available in widely used software packages.

ASL-based 4D-MRA technique for clinical examination

As stated in several chapters, one of the advantages of ASL-based 4D-MRA is that both higher spatial and temporal resolution can be obtained compared to contrast-enhanced 4D-MRA. However, the scan time tends to become longer. When aiming for development of techniques for clinical examinations, it is important to be reminded that many MR examinations have time restrictions due to, e.g. fully booked MR scanners and the finite ability of patients to keep still during the examination. Therefore, keeping the scan time short is one of the most important factors to be considered for a successful introduction of new MRI sequences. At the same time, there is another factor that should be considered about clinical examinations: the condition of patients is not always ideal to obtain the best image quality. For example, patients could be more prone to move during scans. Moreover for ASL techniques, slow blood flow as associated with certain diseases tends to result in poor depiction of flow, sometimes even poorer than the actual flow reduction, thereby causing underestimation or misinterpretation. Therefore, although reduction of scan time may reduce the risk of patient motion, careful optimizations should be done so that the reduction of scan time would not result in a compromise for reliable diagnosis. For example, in the ACTRESS approach as presented in chapter 2, we achieved a reduction of scan time to nearly half of that of the conventional ASL-based 4D-MRA, while avoiding artifacts due to off-resonance effects by optimizing the labeling pulse. However, there is a remaining concern for the patient scans: in ACTRESS approach, it is very important that the control image acquired in the first phase does not contain residual labeled blood from the previous Look-Locker readout cycle. Otherwise, remaining labeled blood in the control image would cancel the ASL signal in those arteries. In the healthy volunteer study, such lowered visualization of arteries with slow flow, such as occipital artery, was minimized by setting a sufficiently long duration of the total Look-Locker readout cycle. However, for patients with even slower or/and delayed flow, special attention is required to use adequate parameter settings for proper diagnosis.

For successful clinical implementation with shorter scan time while avoiding a decrease in diagnostic reliability, such as in the above described example of ACTRESS, a close collaboration with people working in the clinical environment is essential: they have the expert knowledge on what they need, what are essential requirements for diagnosis, and what could be compromised without affecting the clinical usability. In fact, such a collaboration motivated some of studies in this thesis and provided direction to them. Further collaboration is desirable so that the newly proposed techniques in this thesis will be applied to clinical examinations and thereby provide helpful information for diagnosis.

Possible avenues for future research

The application of ASL-based 4D-MRA can be useful for several cerebrovascular diseases, such as arteriovenous malformation (AVM), arteriovenous fistula (AVF) and steno-occlusive disease including Moyamoya disease. Temporal information obtained by 4D-MRA could provide insight about the flow velocity and existence of retrograde flow. Vessel-selective visualization could help to identify the feeding artery of pathology and to assess the function of a bypass artery. Such information could be obtained by using the techniques with relatively short scan time that were developed and optimized in this thesis. However, what is also clinically important but could not be achieved within the context of this thesis projects is improved visualization of even more peripheral arteries with even slower arrival. For example, velocity-selective labeling (1-3) could help an improved visualization of peripheral arteries because the labeling can be applied within these arteries or at least much closer to these peripheral vessels. However, further investigation will be necessary to achieve 4D visualization of inflowing blood.

Also, temporal information obtained by 4D-MRA in this thesis was solely used for visualization, although it could also provide *quantitative* information by using appropriate post-processing, such as kinetic models (4). In the simultaneous acquisition of 4D-MRA and perfusion imaging as presented in chapter 5, there is further potential not only via complementary visual interpretation of macrovascular and microvascular ASL images, but also by calculating additional quantitative measures by combining both measurements.

References

1. Norris DG, Schwarzbauer C. Velocity selective radiofrequency pulse trains. J Magn Reson 1999;137(1):231-236.
2. Wong EC, Cronin M, Wu WC, Inglis B, Frank LR, Liu TT. Velocity-selective arterial spin labeling. Magnetic Resonance in Medicine 2006;55(6):1334-1341.
3. Qin Q, Shin T, Schar M, Guo H, Chen HW, Qiao Y. Velocity-selective magnetization-prepared non-contrast-enhanced cerebral MR angiography at 3 Tesla: Improved immunity to B0/B1 inhomogeneity. Magnetic Resonance in Medicine 2016;75(3):1232-1241.
4. Okell TW, Chappell MA, Schulz UG, Jezzard P. A kinetic model for vessel-encoded dynamic angiography with arterial spin labeling. Magn Reson Med 2012;68(3):969-979.