High resolution Perfusion MRI using SENSE at 7T.

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Introduction

Spin-labeling perfusion imaging at high field poses unique requirements for MRI acquisitions. Because the perfusion contrast is based on subtraction of a labeled from a control scan, excellent temporal image stability is mandatory. However, techniques with good stability, such as single-shot EPI, suffer from prohibitively large distortions at high field, in particular at high spatial resolution. Earlier studies have shown that the magnitude of these distortions can be reduced with accelerated imaging [1]. Spin labeling perfusion benefits from the higher field because of the increase in SNR and the longer T_1 relaxation, resulting in more efficient labeling. In the following, we used SENSE [2] EPI to explore the practical spatial resolution limits of perfusion imaging at 7T.

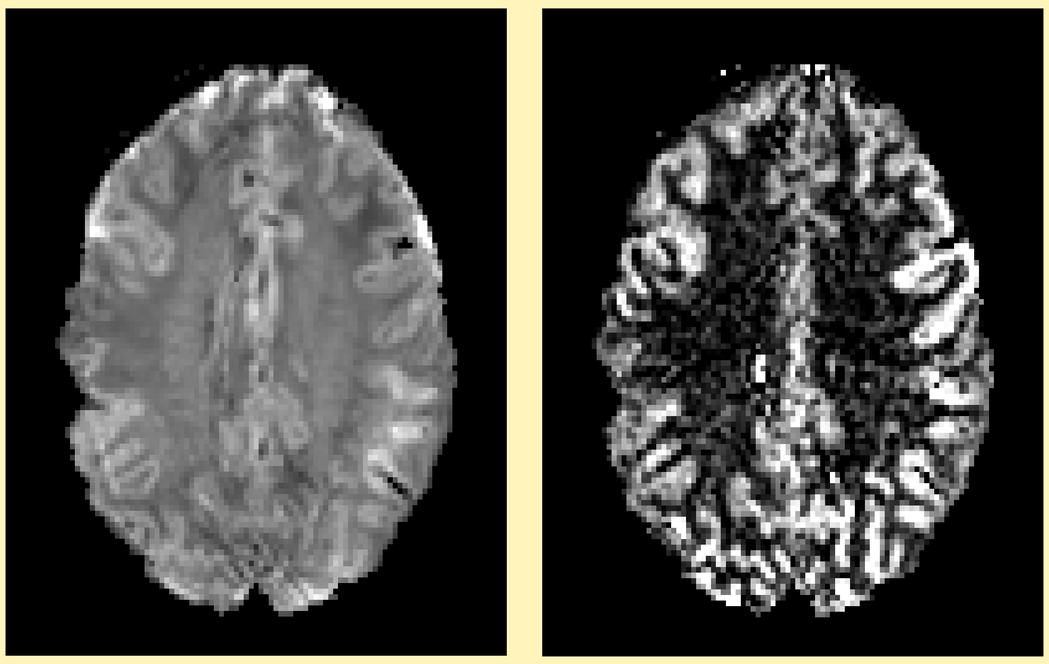

Figure 1.
Example of high resolution perfusion EPI. The nominal in plane resolution is 1.7 mm^2, acquired with SENSE rate 3. The perfusion map is the average of a 6 minute FAIR acquisition..

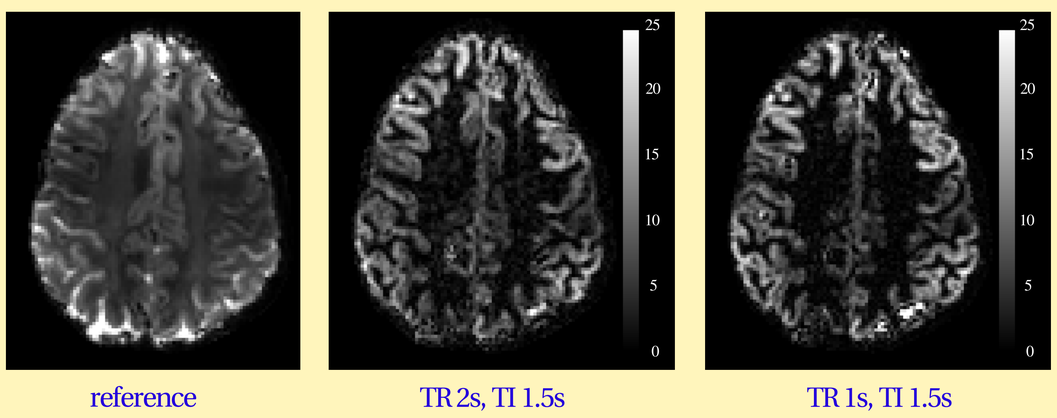

Figure 2.
Example of spin labeling perfusion with SENSE rate 2, showing the average perfusion maps from two studies on the same volunteer. The images are EPI, with 1.7x1.7mm^2 nominal in plane resolution, 2mm slice thickness, 240 shots (4 and 8 minutes scan time), TE 34ms. The scaling of the perfusion maps reflects the SNR of the average perfusion signal.

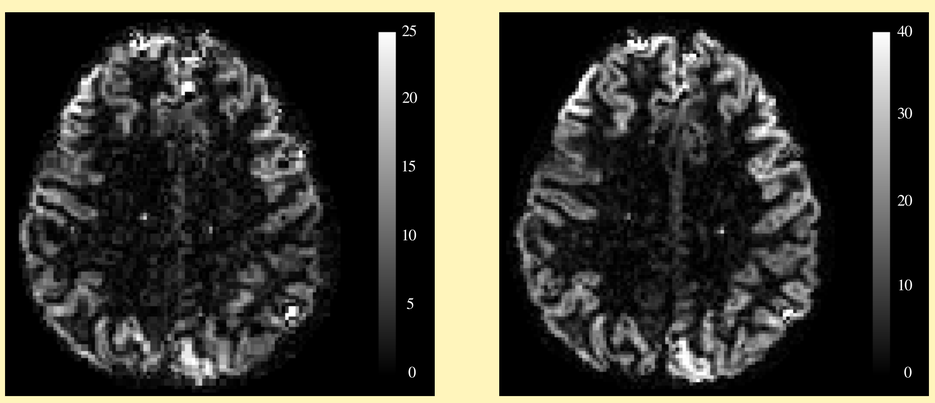

Figure 3.
Two perfusion maps acquired with SENSE rate 3 and two TR and TI times. The images are EPI, with 1.5x1.5mm^2 nominal in plane resolution, 2mm slice thickness, both 5 minutes scan time (150 and 300 repetitions), TE 27.5ms. The scaling of the perfusion maps reflects the SNR of the average perfusion signal.

References

1. R Bammer et.al., Improved diffusion-weighted single-shot EPI in stroke using SENSE. Magn Reson Med **46**:548 (2001).
2. KP Pruessman, et al. SENSE: sensitivity encoding for fast MRI. Magn Reson Med **42**: 952 (1999).
3. JA de Zwart et.al.. Design of a SENSE-optimized high-sensitivity MRI receive coil for brain imaging. Magn Reson Med **47**:1218 (2002).
4. Kim SG. Quantification of relative cerebral blood flow change by flow-sensitive alternating inversion recovery (FAIR) technique: application to functional mapping. Magn Reson Med **34:** 293 (1995).
5. E.C. Wong, W-M. Luh, T.T. Liu, Turbo ASL: Arterial spinlabeling with higher SNR and temopral resolution, Magn Reson Med **44**:511 (2000).

Methods

MRI studies were performed on a 7.0T GE MR scanner equipped with a detunable transmit coil and an 8-channel receive coil (Nova Medical) based on a gapped element design [3]. A FAIR spin labeling technique [4] was implemented with the following parameters: TI (labling time) 1.5s, or 2s, TR 1-4s (to determine optimizal sensitivity), slice thickness 2mm, selective inversion width 20mm, 120 repetitions, total scan time 4-8 minutes. SENSE rates 2 and 3 were implemented at various matrix sizes, the largest of these being a 144x108 matrix size for a 1.5 x 1.5mm^2 nominal in-plane resolution. EPI readout time was 29ms, TE 27ms for rate 3, and 42ms with TE 34ms for rate 2. A flow crusher of 3.5G/cm and 4.5ms duration (b=6.7x$10^6$$m^2$/s) was applied. A full field of view coil sensitivity reference scan was acquired separately, using the same EPI parameters with 2 or 3 interleaves. To reduce shot to shot phase instabilities, these were acquired with a TR of 100ms, flip angle 10^o and averaged over 20s. the perfusion data were calculated as the average pairwise subtraction of the magnitude images and all scaled to the noise level.
To assess the timing of the blood flow, important to judge transit time effects in spin labeling, bolus tracking was performed at 3T using SENSE EPI.

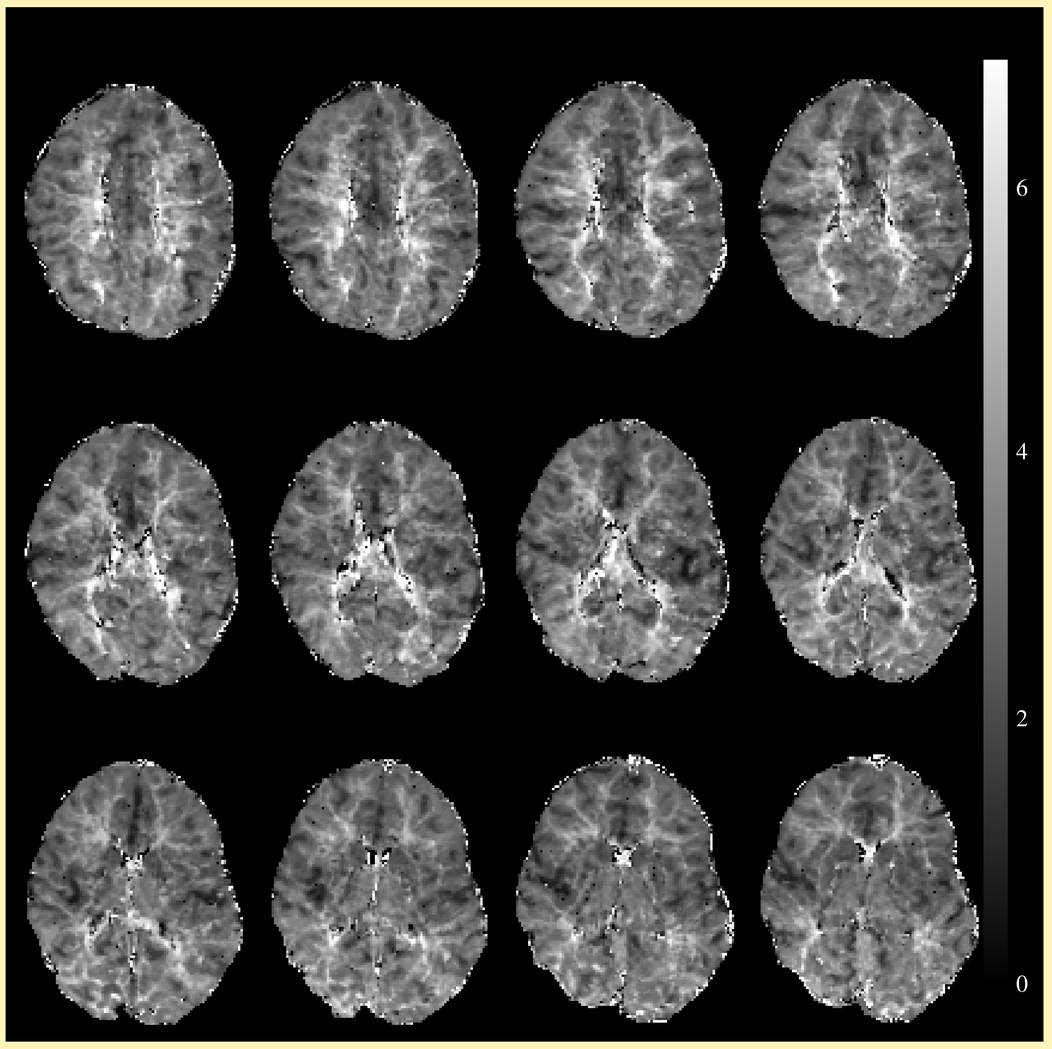

Figure 4.
Relative arrival time (in seconds) of an injected bolus of Gd contrast agent. Measured with rate 2 SENSE EPI, 1.5mm^2 resolution, TR 1s at 3T. The images clearly show that some areas of white matter have a delay in perfusion of several seconds, ie. a very long transit time, resulting in very low spin labeling signal in those areas.

Results & Discussion

The intrinsic image SNR at 7T proved adequate to obtain excellent quality perfusion images at 1.5 x 1.5 x 2.0mm^3 resolution. Baseline image SNR was 80-150 in brain tissue, higher in CSF voxels. In gray matter, perfusion SNR ranged from 10-30. White matter perfusion was not detectable above noise level under these conditions. An example of a single axial slice is shown in Fig. 1. The short 29 ms duration of the EPI readout allowed for minimal distortion in the brain regions studied, which were axial slices at or above the ventricular level.
A comparison between SENSE rate 2 and 3 perfusion results is shown in Figs 2 and 3, which also demonstrate the effects of different TR and TI values. The rate 2 images appear to be comparable to the rate 3 images in terms of deformation etc., as the shimming in these slices was quite good. In both cases there are some SENSE related artifacts of surface arteries causing hot spots in the brain at 1/2 or 1/3 FOV distance. This appears most prominently in the rate 3 images. These stability of the rate 3 images was slightly worse than the rate 2 results.
The data from the different TR and TI times appear very similar, as shown Fig. 2. This suggests a shorter TR (1-1.5s) would be sufficient, provided the TR is long enough to ensure that the inflowing blood being labeled is untouched by the previous pulses, see also [5]. The shorter TR allows for more averages in the same scan time (as in Fig. 3). The stability of the perfusion signal in the short TR scans was also better than the long TR scans, most likely because of the lower background signal.
In all perfusion data the signal in white matter appears very low, if not absent, as is clearly illustrated in Fig. 1. The absence of signal in white matter can be explained by two factors: 1) the blood volume and perfusion in white matter is 3-5 times lower than in gray matter and 2) the transit time in the white matter is significantly longer, reducing the labeling efficiency. This is illustrated in Fig. 4, showing the fitted arrival time of a bolus of contrast agent, measured with SENSE EPI at 3T. This data shows a delay of several seconds in some of the white matter areas.

Conclusion

The high field and the use of a well optimized brain coil allows for 1.5mm resolution perfusion measurements with SNR in the order of 20:1 in gray matter in 5 minute acquisition time.