Spin labeling perfusion MRI with simultaneous transit time measurement

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Introduction

Perfusion imaging based on spin tagging is hampered by low sensitivity and variable label transit times encountered in human brain. The low sensitivity is partly due to the delay times required for the label to reach tissues with different transit times, and for the slice magnetization to relax. In this work a pulsed labeling method is presented that allows reduction of the dead time in the experiment by a) labeling outside of the imaging volume where the label (i.e. the blood) is replaced quickly so that the labeling can be repeated faster and b) by preserving the label over multiple acquisitions; this in contrast to (1) where a fast perfusion method is proposed without preserving the label. In addition switching between labeling and reference acquisitions is controlled by a m-sequence to obtain transit time information.

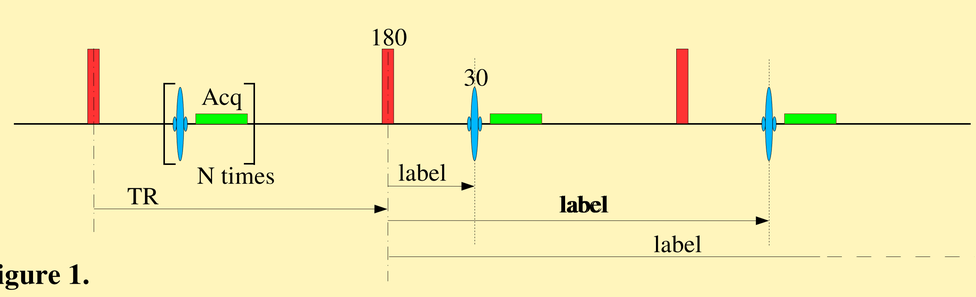

Figure 1.
The sequence. The labeling pulse has a direct effect on the following acquisition and perfusion effect on subsequent TRs. The 180 degree labeling pulse is either a label or a reference inversion pulse , depending on the m-sequence bin value for that TR.

Sequence

Preserving the label is achieved by reducing the imaging pulses to 30°, which results in 50% signal reduction, but leaves 87% of the label intact for the next TR. Each repetition of the sequence (Fig. 1) consists of an adiabatic FOCI labeling pulse, some delay, and a multi-slice EPI acquisition followed by a second delay. The labeling pulse inverts a 130mm thick slice located just under the imaging volume. During reference scans the slice thickness is reduced to 13mm while the center location is maintained the same. To reduce the slice thickness, the FOCI bandwidth is reduced, while selection gradient amplitude is kept constant. This allows reduction of MTC effects in all slices by keeping the frequency offsets constant. Remaining MTC effects due to non-uniformity of the MT spectrum could be reduced by adjusting the offset frequency of the reference pulse (see Fig 2).
Switching between label and reference was controlled by a m-sequence. A m-sequence is a pseudo random binary series (1's and 0's), which can be generated with a feedback shift register. Its autocorrelation is close to zero for all time lags unequal to zero. This allows for a simple correlation analysis to calculate the perfusion signal as function of delay time after the label pulse. The correlation at different time lags allows direct analysis of residual MT effects, which mostly affect the first volume, as well as transit time delays.

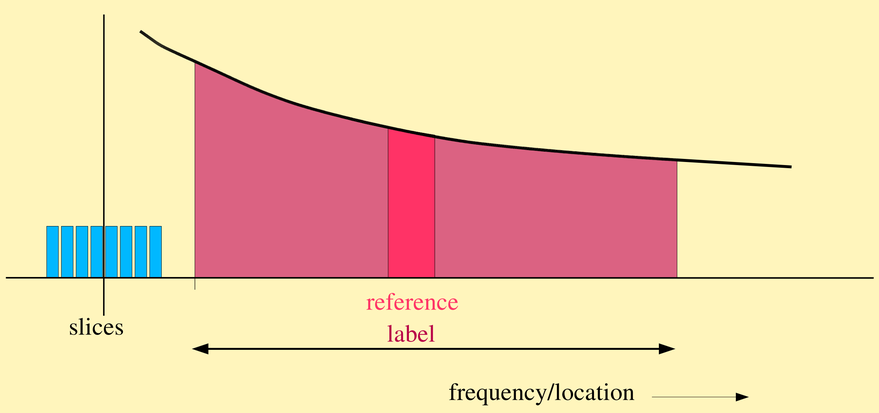

Figure 2.
Schematic diagram of the frequency spectrum representing the image slices, label inversion slab and reference inversion slab. The curve represents a MT spectrum. The reference is slightly shifted with respect to the reference to compensate some of the non-uniformity of the MT spectrum.

Methods

The design was tested on several volunteers, scanned after obtaining informed consent under IRB approved protocol on a GE 3T scanner with a 16 channel Nova head coil and home build digitizer (2,3). A number of different labeling parameters was tested, while the optimal setting (see below) was tested on two volunteers. Scan parameters:
image acquisition using EPI with 50% ramp sampling, slice-to-slice TR 75ms, echo time 32ms, overall TR 1s, delay before inversion 340ms, resolution 96x72 pixels over 220x165mm filed of view, 8 slices of 3.5mm +0.5mm gap, 600 repetitions. A 255-bin m-sequence was used, extended to 300 bins by repeating the first 45, and followed by its inverse. The data was analyzed by combining the correlation of the pixel time courses in the first and second half with the m-sequence.

References

1) Wong et.al., 'Turbo ASL: Arterial spin labeling with higher SNR and temporal resolution', Magn. Reson. Med. **44**:511 (2000).
2) de Zwart et.al., 'Signal to noise and parallel Imaging performance of a 16-channel whole brain coil array at 3.0 Tesla', Magn. Reson. Med **51**:22 (2004).
3) Bodurka et.al., 'A scalable multi-channel MRI data acquisition system', Magn. Reson. Med **51**:165 (2004).

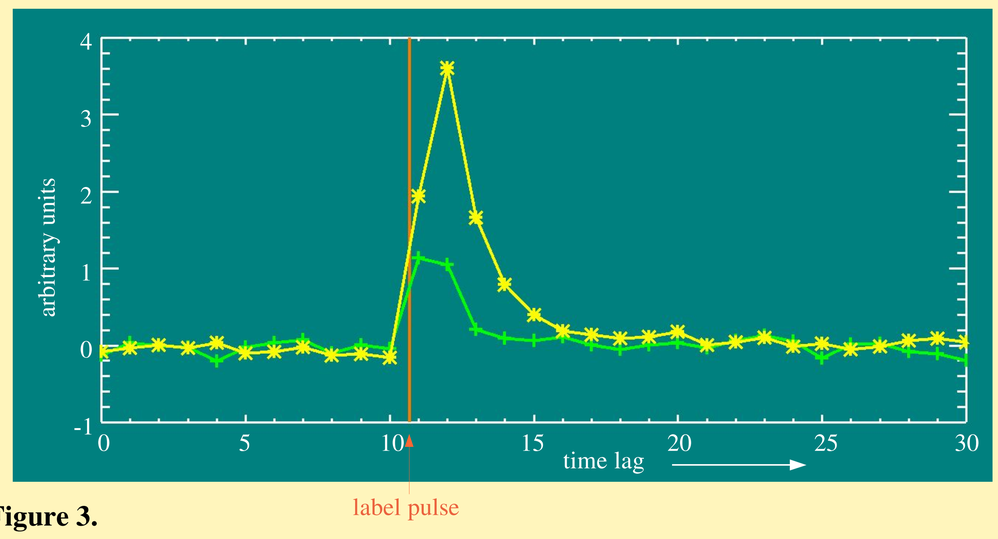

Figure 3.
Example of the resulting correlation in a gray matter (yellow) and a white matter voxel (green). The plot shows 30s out of the correlation with the labeling m-sequence, the time of the labeling pulse is indicated in orange. The white matter time course is both lower and shorter, reflecting the differences in MT and perfusion compared to gray matter.

Results & Discussion

The plot in figure 3 shows an example of the resulting correlation for two voxels. The white matter voxels shows a lower and faster response to the inversion label, as it has a stronger MT effect and much less perfusion signal. The shape and timing of these response curves contains information on the relative contribution of the remaining MT effect and the transit time delays of the label. The MT effects start immediately after the inversion pulse, the perfusion signal is delayed by the transit time, both signals decay with T_1 relaxation. For a very accurate transit time measurement therefore one will need the local T_1 , which itself is difficult to estimate accurately. However, correction of large transit time effect, as for example occur in stroke, should be possible based on known gray and white matter T_1 values.
Figure 4 shows the resulting correlation maps for four slices and three time lags. The first time lag shows the direct effects of the label pulse on the image slices, as for this data set the reference frequency was not adjusted. This adjustment of the reference inversion frequency will not be perfect for all slices, because of the the different offsets, so the direct measurement of the effect will still be useful.
The two subsequent time lags show a clear perfusion signal. The SNR of the gray matter perfusion map was 50-100, depending on location. Despite the reduced TR, the efficiency of the sequence is similar to a standard pulsed labeling technique, because of the lower acquisition flip angle. To improve the timing resolution and efficiency, a second set of imaging pulses could be added in each TR, or the TR could be shortened as most of the labeled blood in the inversion slab will be in larger arteries which in which the blood is replaced faster than on second.
The main advantage of the method is that is a allows the direct observation of variable transit time delays of the perfusion label and MT effects, and the potential for separating these from the perfusion signal.

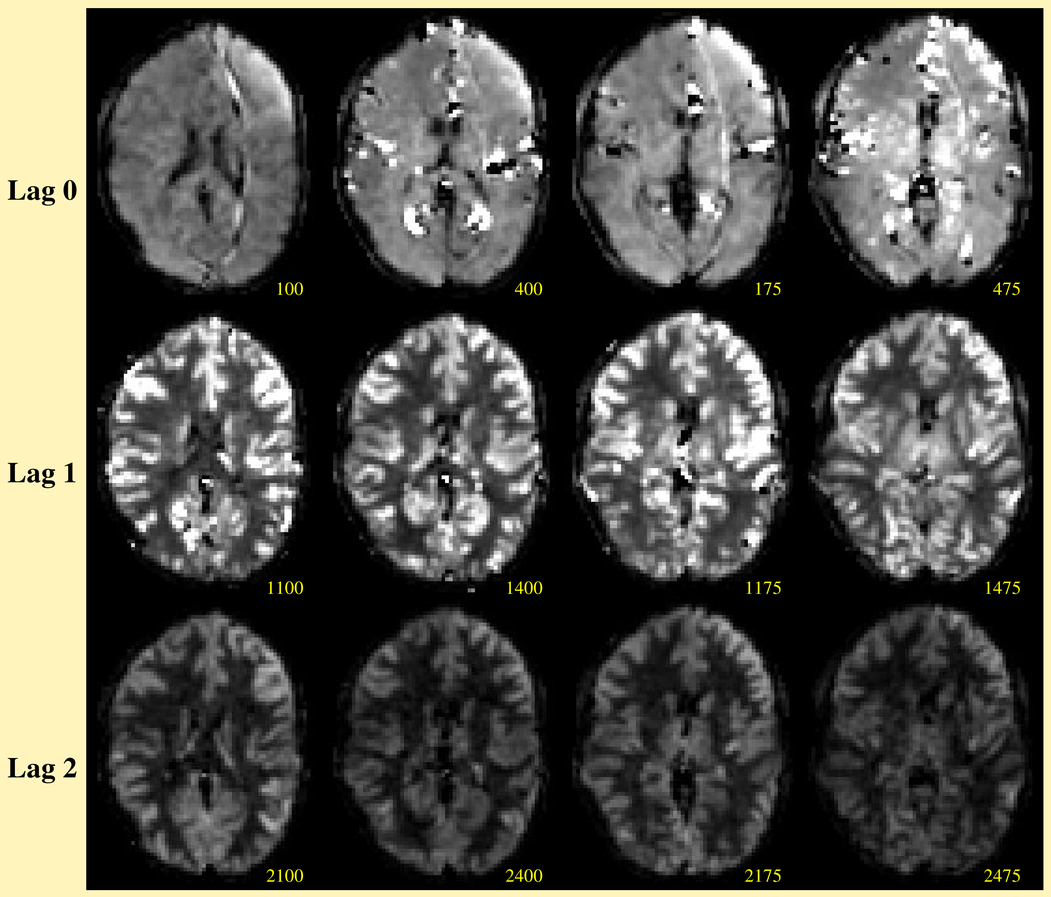

Figure 4.
Example of resulting correlation maps, showing four different slices. Top to bottom are three time lags: right after inversion, and one and two seconds later. The number next to each image indicates the time after the label pulse in ms.