High resolution Gd-DTPA bolus tracking at 3T

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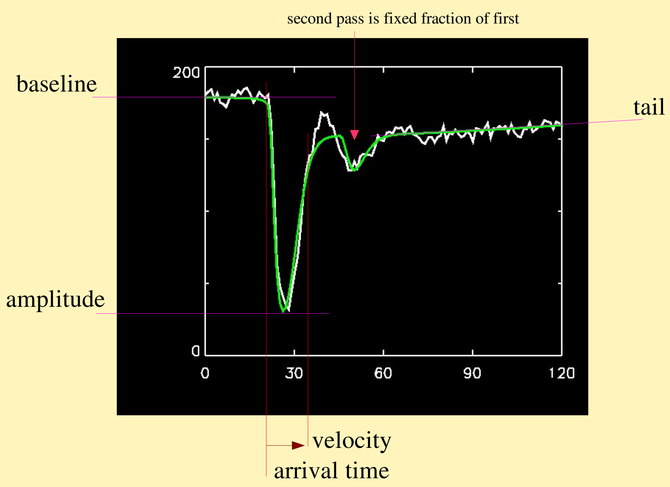
Introduction

Bolus-tracking (BT) using intra-vascular susceptibility contrast agents allows the study of cerebral hemodynamics under normal and pathologic conditions (1). After intravenous injection of Gd-DTPA, the passage of the contrast bolus through the cerebral vasculature can be monitored using rapid T_2^*-weighted imaging. With the required scan speed of about 1 image/s, the spatial resolution of BT MRI is limited to 2-3mm by gradient switching speed and SNR. This resolution is inferior to that of anatomical scans and results in reduced sensitivity and accuracy because of partial volume effects. In the following we have tried to improve BT resolution to 1.5mm through SENSE and the increased SNR available with and optimized 16-channel coil array (2). We demonstrate the feasibility of estimating hemodynamic parameters with high precision, even in low-perfusion areas such as (deep) white matter.

Methods

Six volunteers were scanned after providing informed consent, under and IRB approved protocol. The study was performed on a GE 3T scanner (gradient slew-rate 150T/m/s), with a 16-channel phased array coil and receiver built in collaboration with Nova Medical (2,3). A power injector (Medrad Spectris) was used to administer a bolus of Gd-DTPA contrast agent (Berlex Magnevist) through an angiocatheter in the antecubital vein. A standard clinical dose was used (0.2ml/kg) at a rate of 10ml/s. The imaging sequence was a locally developed EPI, with 144x112 voxels, 12 slices, FOV 220x171mm, slice thickness/spacing 1.5/0.5mm for a nominal resolution of 1.53x1.53x1.5mm^3. With SENSE rate 2, 4us sampling rate and 50% ramp sampling the total acquisition window was 46ms. Other parameters: TE= 40ms, TR=1s, 180 repetition, injection start at 30s. After image reconstruction, the time series were fitted with an empirical bolus function including the 'tail' effect after passage of the bolus. Five parameters were fitted: baseline amplitude, relative bolus amplitude, arrival time, speed and relative tail amplitude, see Fig. 1. Delay and relative amplitude of the second pass were set to 24s and 12% of first pass after initial inspection of the data. A simulation based on average gray and white matter curves with addition of 10000 noise realizations was performed to estimate the precision of the fitted parameters. The noise level was derived from an acquisition without any RF pulse.

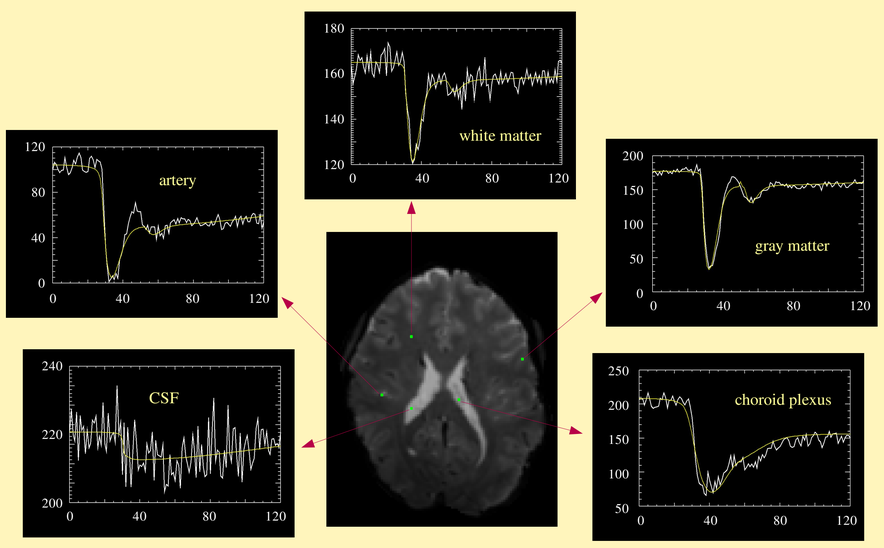
Figure 1. The fit function and its five parameters.
The signal is modeled as:
$s = a_0 e^{-c(t)}$,
where the concentration c is:
$c = a_1 \tau^3 e^{-\tau/2}$,
where τ is time scaled for start time and width. The second pass is a scaled and shifted version of the first, the tail is a smoothed step times a exponential decay.



Results

An example of the bolus passage in various tissues is shown in Fig. 2, demonstrating the high SNR, sufficient for a reliable measurement in white matter. The fitting procedure converged in more than 99% of the image voxels, the exception being mostly voxels in or very close to the ventricles. As expected, the CSF shows very little effects, except in the choroid plexus where the contrast appears to wash out much slower. The arterial voxel is essentially zero on the top of the bolus. The spatial average variance, scaled to instrument noise level, was 37.6 for the raw data, 4.0 for the residue after fitting and 1.99 for the baseline before the bolus.
An example of the resulting parameter maps is given in Fig. 3, showing relative bolus amplitude, the full width at half maximum (FWHM) arrival time and the tail effect. The start time showed a 4-6s contrast from cortex to deep white matter. The FWHM showed a similar contrast, but notably different in distribution. The two were not correlated. The baseline SNR and estimated precision are reported in Table 1, bases on averages over all volunteers. Note the time parameters can be estimated much more accurately than the 1s TR of the measurement.

Figure 2. A sample of voxel time courses, showing the bolus passage in various voxels. Note the second pass in the gray matter and arterial voxels and the SNR in the white matter. The yellow lines are the fitted curves.



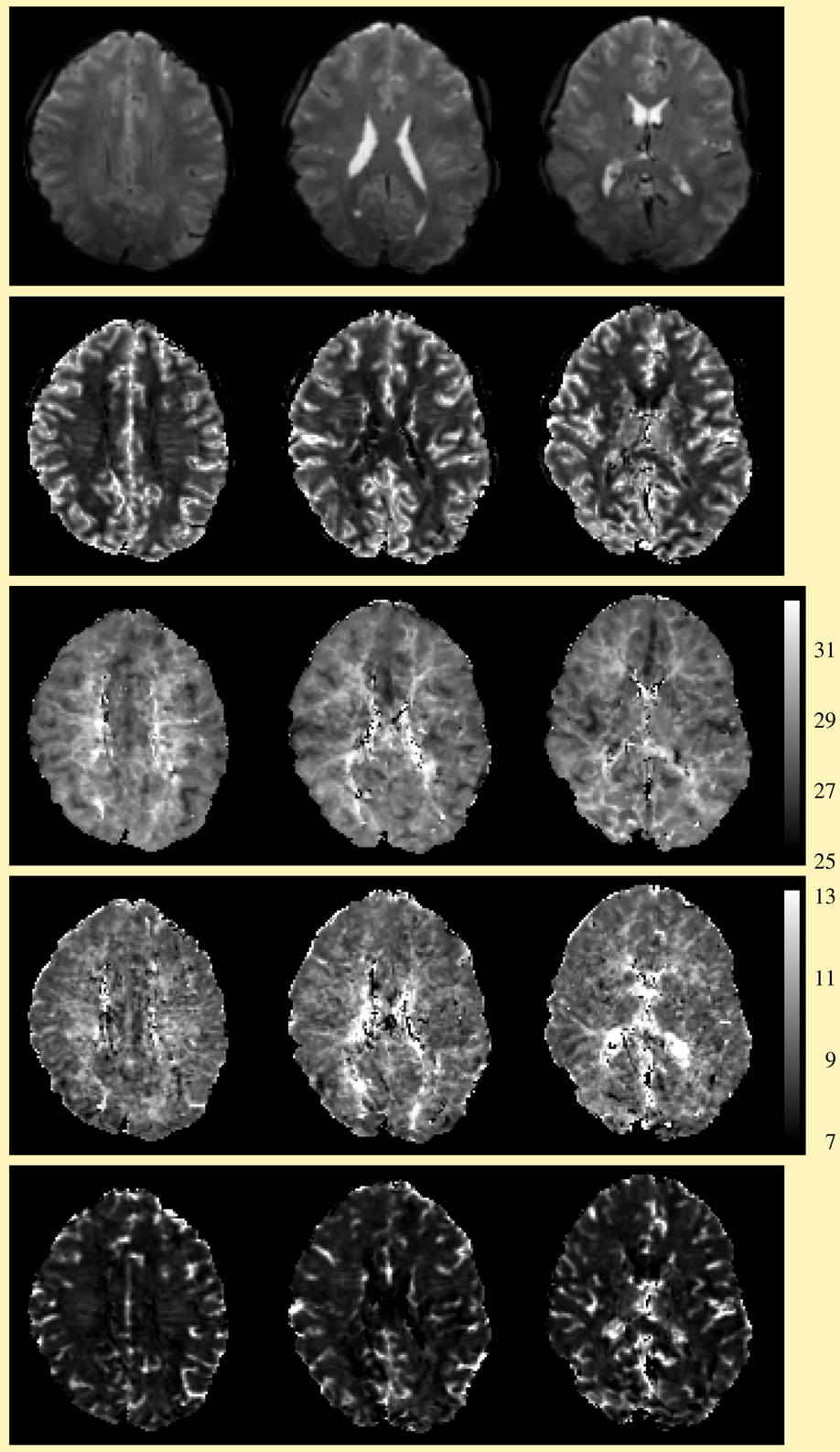
Discussion

The results show that high resolution bolus tracking is feasible with a 16 channel coil on a 3T system, and that a standard clinical dose results is sufficient to reliably estimate rCBV and arrival time throughout all white matter. The high spatial resolution allows for more accurate estimation of flow parameters by reducing partial volume effects, while the high timing precision may facilitate detection of abnormal flow. The precision is high enough to lengthen the TR to 2s or more, which would allow imaging 24 slices.
The used fitting function explains most of the variance in the data. Fitting (and using) the arrival time seems to make more sense than the more usual time to peak value, as it appeared to be uncorrelated to the width. The time to peak, which is equal to the arrival time plus half the width obviously does have this correlation.
The arrival time of the bolus in the white matter shows a variation of delays of several seconds. It is unlikely the shape of the bolus is not affected by this delay and therefore the input function for the white matter voxels is uncertain. Together with the difficulties in determining an arterial input function, related to the non-linear nature of the contrast mechanism and the lack of signal during the peak of the bolus (see Fig. 2), this makes it very hard to calculate the true transit time in the white matter voxels. Secondly, the long delay times mean that perfusion measurements with arterial spin labeling will have very little label left when the blood reaches the (deep) white matter, decreasing the already low sensitivity substantially.

Table 1. The SNR and estimated precision of the fitted parameters

	SNR	*basline*	*amplitude*	*time*	*speed*	*tail*
gray matter	58	0.33%	2.2%	80ms	1.7%	0.4%
white matter	50	0.34%	4.8%	240ms	4.9%	1.0%

Figure 3. Example of the SENSE-EPI images and resulting bolus tracking parameter maps. The first volume of the time series is added for anatomical reference.



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