Ultrafast Simultaneous Detection of Changes in Perfusion and BOLD Contrast

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Introduction. The BOLD contrast depends on changes in both cerebral hemodynamics and oxidative metabolism. A combined measurement of changes in perfusion and BOLD contrast offers the possibility of separating these phenomena and of estimating changes in cerebral oxygen consumption, as recently demonstrated by using imaging techniques such as FAIR (1, 2) or BASE (3). Unlike FAIR or BASE, the novel spin labeling technique we describe here, allows simultaneous detection (SIDE) of changes in perfusion and BOLD contrast by combining a single slice-selective inversion pulse with dual echo EPI. The advantage of SIDE is, that no spatial or temporal mismatch between perfusion and BOLD weighted images can arise.

Methods. Eight healthy volunteers were investigated using a 3 Tesla whole body system (Medspec 30/100, Bruker, Ettlingen, Germany). For visual stimulation a simple visual search task was used. The subjects were first given a cue comprising an 'L' shape of a given orientation. After a delay of 1.2 s, a 10 x 10 array of randomly rotating 'L's was presented for a period of 2 s. Then four of these shapes became stationary while the remainder continued to rotate. At this point the subjects were to determine whether the orientation of any one of the stationary shapes matches that of the cue and give a yes / no response using a two button key pad. The stimulation protocol consisted of 5 blocks of control interleaved with 5 blocks of visual stimulation, with a total duration of 5 minutes.

The SIDE technique was implemented with a slice-selective hyperbolic secant inversion pulse to generate perfusion contrast (4). Following the inversion time, T_{inv} = 1.9 s, a slice-selective 90° pulse was applied and the resulting transverse magnetization was read out by a dual echo EPI sequence, consisting of a spin echo image followed by a gradient echo image. The corresponding echo times were TE1 = 19 ms and TE2 = 35 ms. Further imaging parameters were: FOV = 22.4 cm, SLTH = 5 mm, matrix size = 64 x 64, sampling bandwidth = 200 kHz. The spin-echo image is sensitive to changes in (CBF), whereas the gradient-echo image is sensitive to changes in both CBF and T2*. Due to the short TE1 time used in this experiment, T2 related signal changes as reported in (1) are negligible. Changes in the cerebral blood flow between periods of visual stimulation and control and absolute T2* values were calculated from the signal intensities of the spin and gradient echo images, S1 and S2:

$$\Delta CBF = CBF(st) - CBF(co) = C\,(S_1(st)/S_1(co) - 1)\ ,$$

$$T2^* = TE_2 / \ln(S_1/S_2)$$

The scaling constant, C, is given by

$$C = \frac{\lambda\,(1-(2-e^{-T_{rec}/T1})\,e^{-T_{inv}/T1})}{(2-e^{-T_{rec}/T1})\,e^{-T_{inv}/T1}T_{inv} - e^{-T_{rec}/T1}\,e^{-T_{inv}/T1}T_{rec}}$$

In one group of subjects (n = 4), the inversion and the recovery time were $T_{inv} = T_{rec} = 1.5$ s, yielding a repetition time (TR) of only 3 s. In another group of subjects (n = 4) these parameters were: $T_{inv} = 1.9$ s, $T_{rec} = 4.1$ s, and TR = 6 s. For the intrinsic T1 relaxation time of gray matter at a field strength of 3T we used a previously measured average value of 1.25 s. The brain / blood partition coefficient for water was assumed to be $\lambda = 0.9$ ml/g (5). Image time series were corrected for bulk motion and a linear baseline correction was applied. Functional activation maps were calculated by means of a correlation analysis ($r > 0.5$).

Results. The activation maps calculated from the spin echo (S1) and gradient echo (S2) images obtained in a single subject are depicted in Fig. 1. Figure 2 shows the corresponding mean time courses of S1, S2, ΔCBF and T2*, which were calculated from all pixels that exhibited a significant increase in both S1 and S2. TR was 3s. The average changes calculated over all activated regions in all subjects were: S1 = 1.27 ± 0.13 %, S2 = 2.68 ± 0.48 %, ΔCBF = 50.3 ± 4.8 ml/min/100g and ΔT2* = 1.39 ± 0.46 ms. There was no significant difference between subjects imaged with TR = 3 s and TR = 6 s.

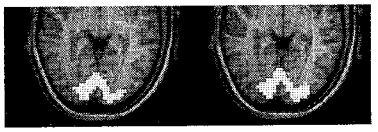

Fig. 1. Functional activation maps calculated from S1 (left) and S2 (right)

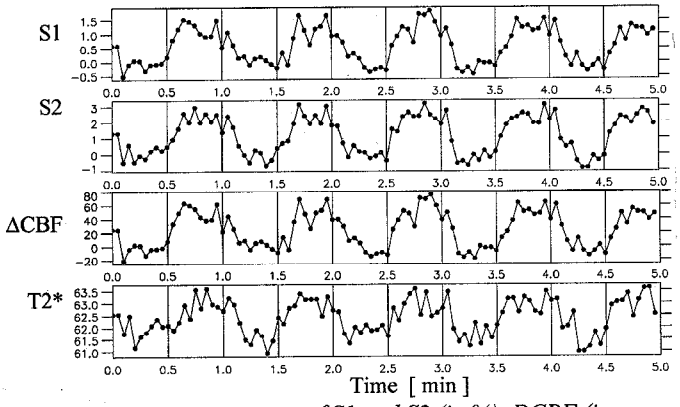

Fig. 1. Mean time courses of S1 and S2 (in %), DCBF (in ml/min/100g) and T2 (in ms).*

Summary. This study has demonstrated the feasibility of simultaneous detection (SIDE) of changes in perfusion and BOLD contrast with a high temporal resolution of 3s. Furthermore, it has been shown that quantitative changes of the cerebral blood flow (CBF) and the effective transverse relaxation time (T2*) can be calculated from the acquired image data. Since perfusion and BOLD weighted images are generated from the same longitudinal magnetization, no errors due to spatial or temporal mismatch can arise.

References

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