

Perfusion-based High-Resolution Functional Imaging in the Human Brain at 7 Tesla

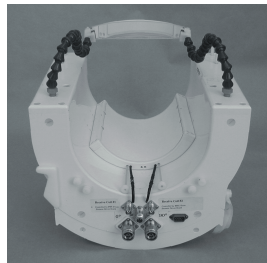
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In this paper, CBF-based functional imaging is reported at sub-millimeter resolution (0.9 mm) in humans for the first time. High sensitivity was made possible by signal-to-noise gains at the high magnetic field of 7 Tesla and by using a novel RF combination coil design. In addition, 0.9-mm in-plane resolution with gradient-echo echo-planar imaging was achieved *in a single-shot* by reducing the field-of-view. Functional CBF data were compared with functional BOLD data to reveal that the CBF response was more localized and that, for CBF, large contrast-to-noise gains were obtained at high spatial resolution.

Introduction Perfusion-based MRI measures cerebral blood flow (CBF) at the capillary level and can be used for functional studies based on the tight spatial coupling between brain activity and blood flow. Obtaining functional CBF maps with high spatial resolution is a major challenge, because the CBF signal is intrinsically low and the signal-to-noise ratio is critical. Here, high-resolution CBF maps were obtained with voxel sizes as small as $0.9 \times 0.9 \times 1.5 \text{ mm}^3$ in the human brain.

Methods Single-shot EPI was performed on a 7T/90 cm system (FOV 3.2/12.8 cm, TE 22 ms, axial plane). An actively-switched combination coil was used with a half-volume transmit and a 6-cm quadrature receive coil pair [1]. With the zoomed imaging technique BISTRO [2], the FOV was reduced to 3.2 cm (Fig 2). CBF contrast was generated using FAIR with $TI = 1.5 \text{ s}$ and $\tau = 1.5 \text{ s}$. The image TR for fCBF and IR-prepared BOLD imaging was 6 s (2 excitations).



Results A high-resolution CBF map is shown in Fig. 3 with gray matter boundaries overlaid. As expected, the CBF contrast was low in white matter and high between gyri and inside gray matter. Robust functional activation was detected with percent signal changes $>100\%$ for fCBF and $>10\%$ for fBOLD (see also Fig 4). fCBF maps did not show activation in sinuses, large vessels, or in the space between the gyri. In contrast, fBOLD maps were more wide spread with largest t-scores and percent changes residing between gyri. This observation is consistent with fCBF maps being more localized to gray matter while fBOLD maps are less due to contributions of proximal draining veins.

fCBF and fBOLD were compared at different voxel sizes, ranging from 32 to 1 mm^3 (Fig. 5). Contrast-to-noise was similar for fBOLD ($t = 9-11$), but increased significantly with decreasing volume for fCBF ($t = 7-21$). Similarly, percent changes increased more rapidly for fCBF (50-250%) than for fBOLD (3-9%). These data are consistent with the hypothesis that partial volume effects are more pronounced for fCBF, which is confined to gray matter, and less prominent for T_2^* BOLD because it is less specific. The highly resolved images obtained in this study verify this conclusion. In other words, these data indicate that the point spread function of fCBF is narrower than that of T_2^* fBOLD. This is consistent with findings in other human and animal studies [3,4] that fCBF signal is located in the capillary bed.

In summary, high-resolution CBF-based fMRI in the human brain was demonstrated. Sub-millimeter spatial resolution resolved different tissue types and greatly reduced partial-volume effects. For CBF-based fMRI, considerable contrast-to-noise gains were found at higher spatial resolution.

These developments for high-resolution fMRI can improve neuroscience studies and diagnostic imaging. Based on the initial experimental data in humans, it is suggested that neuronal activity is better captured by functional CBF than T_2^* BOLD maps at high

resolution. This is significant for the elucidating localized brain function in humans, and clarification of the physiological basis of functional neuroimaging.

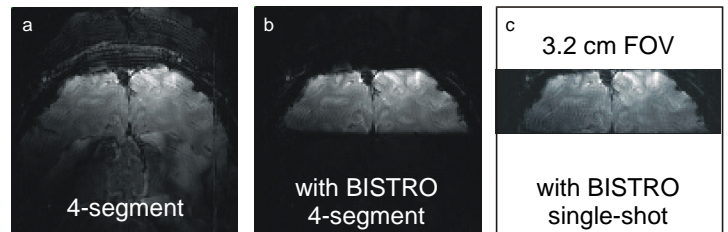


Fig. 2: Zoomed echo-planar imaging with reduced FOV

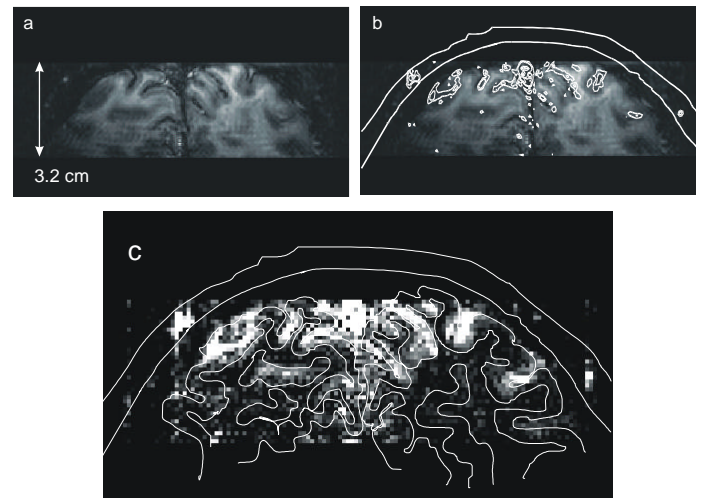


Fig. 3: (a) IR-EPI, (b) CBF contours, (c) high-res CBF map

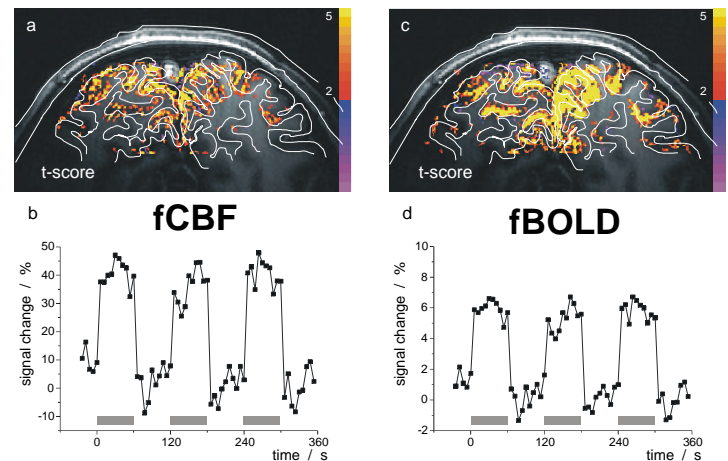


Fig. 4: functional CBF and BOLD maps/ time courses

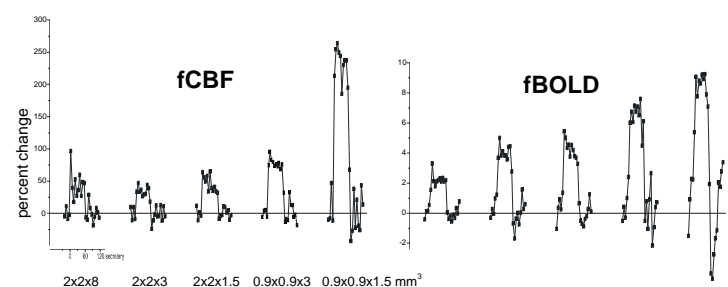


Fig. 5: Signal changes with decreasing voxel size ($32 - 1 \mu\text{l}$)

References 1. Adriany G et al, ISMRM 2000, 1097. 2. Garwood M et al, MRM 2001, 1095. 3. Luh WM, MRM 2000, 137. 4. Duong T, PNAS 2001, 10904.

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