Magnetic Resonance Phase Imaging of the Human Brain at Different Degrees of Blood Oxygenation

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Introduction

MR imaging techniques that utilize blood as an endogeneous contrast agent range from fMRI [1] to high-resolution MR venography [2]. More recently, investigations of the response of healthy and pathological tissue to breathing oxygen or carbogen have gained importance [3]. We applied a high resolution susceptibility sensitive sequence and used its phase information to directly visualize changing magnetic field distributions around venous vessels in response to changing blood oxygenation triggered by carbogen or oxygen breathing.

Methods

High resolution, T2*-weighted, single echo images of three healthy subjects were acquired on a 1.5 T system (Magnetom Vision, Siemens, Erlangen, Germany) with a 3D, first order velocity compensated gradient echo sequence [2] using a quadrature transmit/receive bird cage head coil (TR\TE\α=67 ms\40 ms\25°, FOV = 25.6 cm x 19.2 cm x 6.4 cm, Matrix = 512 x 384 x 64). During the scans air (1st scan), carbogen (95%O_2, 5%CO_2) (2nd scan) and pure oxygen (3rd scan) were supplied through a face mask for each subject. Phase and magnitude images were reconstructed from raw data. Phase images were unwrapped [4] and high-pass filtered to eliminate contributions from static magnetic field inhomogeneities which vary over large spatial distances. Views of the phase distributions around veins perpendicular to B_0 and minimum intensity projections over several phase images were computed.

Results

Fig.1 shows the effects of different blood oxygenation on the magnetic field distribution around venous vessels. Compared to air (a), phase contrast of venous vessels is slightly decreased during oxygen (b) and largely decreased during carbogen (c) breathing, while contrast between tissues of different iron content (e.g. red nuclei *vs*. gray/white matter) is left unchanged. Comparison between the cross sectional views of a vein (d-f) and the theoretical field distribution around a cylinder supports the approximation of blood vessels as cylinders of infinite length. These images (d-f) show the typical features of the magnetic field around a long cylinder with a different magnetic susceptibility than its surroundings. Due to the lower blood oxygen concentration during air breathing the vein in (d) is more paramagnetic than in (e) and (f). Field inhomogeneities are therefore much more pronounced and extend farther into the parenchyma. Of note is the constant phase distribution inside the vessel, as expected. In the basal ganglia, where the precession frequency is mainly determined by tissue iron content rather than blood oxygenation, no change in precession frequency between the breathing protocols was observed (Fig 1a-c).

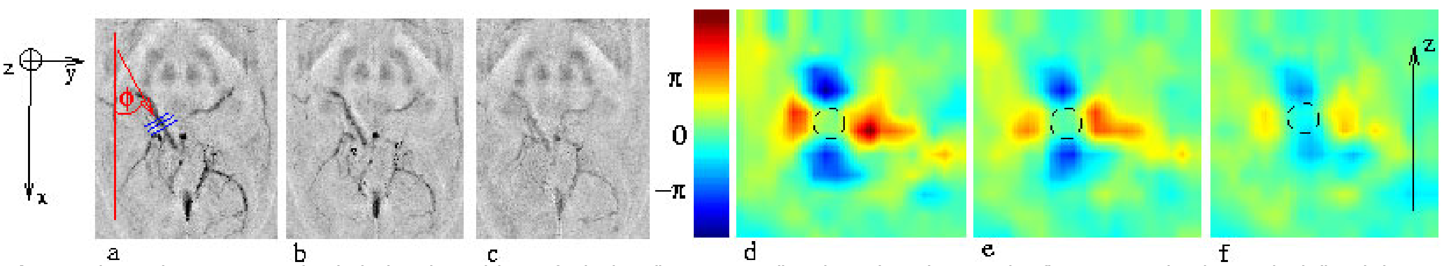

Fig 1: Phase images acquired during breathing of air (a, d), oxygen (b, e) and carbogen (c, f). Images (a-c) are (axial) minimum intensity projections over 6 mm (ROI = 8.2 x 6.9 cm). Images (d-f) are cross sectional views (along the direction indicated by the red arrow in image (a)) of the phase distribution in a ROI of 11 mm x 11 mm around the v*ena temporalis interna.* The approximate location of the vein is indicated by a small dotted circle in (d-f). Note that low phase values correspond to increased field strength and vice versa.

Discussion

High resolution susceptibility weighted phase imaging allows to visualize the blood oxygenation dependent distribution of the magnetic field around venous vessels This may be valuable to predict the effects of radiosensitization of tumors with carbogen [3,5,6]. Although phase imaging is very sensitive to changes in blood oxygenation or to susceptibility changes in general, direct assessment of changes in vessel diameter as a consequence of hypercapnia or hyperoxia may require even higher spatial resolution. Furthermore, investigations of finite vessel segments at arbitrary orientations with respect to B_0 (e.g. veins within tumors or veins draining tumors) require more complex field calculations.

References

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