Improved vessel localization in Magnetic Resonance Venography at 3T using multiple-echo image combination and asymmetric triangular filter

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Introduction

The venographic SWI method proposed previously [1,2], allows the visualization of vessels located within a minimum intensity projection (mIP) slab with a 14-20 mm thickness. This resolution is not sufficient for fMRI studies, when areas with large vessels should be removed from the analysis. We explore the use of multiple-echo images and alternative phase masking methods and show that, with appropriate phase-mask filtering, mIP projections of 4 mm (with the filter applied once instead of the 4^{th} power of the standard approach) can be generated without substantial loss in vessel visibility, thus enabling the use of these venographic images in fMRI studies.

Materials and method

Six healthy individuals gave their informed consent to participate in these study, approved by the local ethics committe (three females, three male, 22-26 years). For each subject, magnitude and phase k-space data were obtained with a 3D first-order velocity compensated multiple gradient echo sequence (MEDIC3D, Multiple-Echo Data Image Combination) with a voxel size of ($0.5x0.5x1mm^3$) on a 3 T (Allegra, Siemens Medical Systems, Erlangen, Germany). Sequence parameters were optimized in a pilot study on three volunteers to obtain venographic images within a reasonable acquisition time, in order to minimized movement artefacts. The selected sequence parameters were: TR=42ms, flip angle: 30° and BW: 79 Hz/px, TE=27 ± 6ms. Reconstruction was performed off-line by in-house code developed in MatLab v7 (Mathworks Inc, Natick, MA). From simulations of different vessel orientations and blood volume fractions within an anisotropic voxel of $0.5x0.5x1mm^3$ (Fig.1), specific features of the phase effect were determined that then were used for designing alternative masking methods.

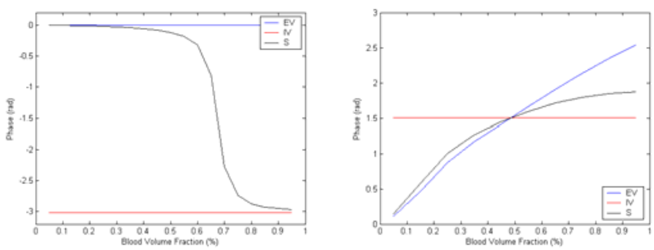

Fig.1: Simulation of the phase in an anisotropic voxel (0.5x0.5x1mm) crossed by a macro-vessel parallel to the static magnetic field B_0 (left) and perpendicular to B_0 (right) as a function of the Blood Volume Fraction (BVF). Note the maximum phase changes of $-\pi$ for parallel and $\pi/2$ for perpendicular vessels.

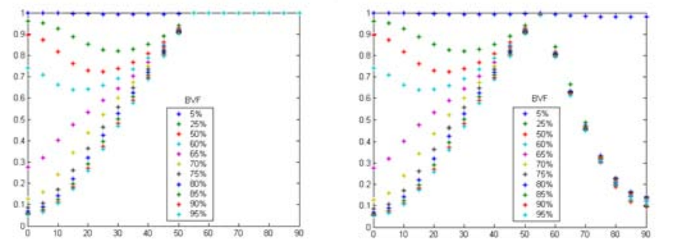

Fig. 2: Simulations illustrating how the standard negative (left) and the proposed asymmetric triangular filter (right) act on the phase of a voxel crossed by a macrovessel, as a function of the vessel orientation and the blood volume fraction. Abscissa: angle in degrees between the vessel and B_0, ordinate: phase value after scaling. The behaviour of the two approaches is the same for angles below the magic angle, while vessels at greater angles are affected by the asymmetric triangular filter only.

Results

The advantage of the combined echoes is an over-all gain in the available information (i.e. increased dephasing effect and increased SNR) enabling venographic projections over thin slices (mIP across only 4mm, instead of the 10-20 mm of the standard approach).The venographic contrast-to-noise was further increased by the use of an asymmetric triangular filter, designed by the specific features of the phase effect evidenced in simulations (Fig 1). Simulations showed how this alternative filter increases visibility for all vessel orientations except those at the magic angle (55°) (Fig 2). The asymmetric filter leads to an improved CNR when compared to the standard approach and only one multiplication of the phase mask was necessary (Fig 3). It can be noted that the standard approach of applying the negative filter four times at the low CNR available for thin slice mIP substantially increases noise.

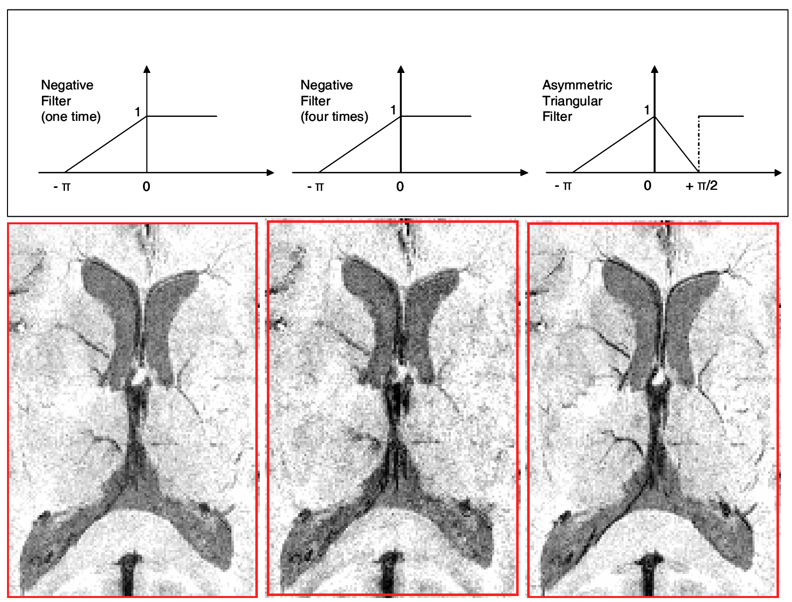

Fig. 3: Details of mIPs across 4mm obtained by multiple echo combination and different phase-mask filters. From the left: negative filter applied once and four times [1,2], asymmetric triangular filter applied once.

Discussion and Conclusions

It is well-known that the BOLD-related phase effect depends on both the blood volume fraction within the imaging voxel and the vessel orientation with respect to the static magnetic field. Both factors determine the relative weight of the intravascular (IV) and extravascular (EV) components in the total signal (S). Since the brain contains vessels of varying size and orientation, the phase value can change its sign. Other factors that also may influence the phase effect are $\Delta\chi$, oxygen saturation fraction and hematocrit [3]. Therefore the proposed approach that scales the phase both in positive and negative space seems to enhance vessel visibility more than the standard approach (negative mask applied four times). The proposed venography approach may be helpful for estimating the contribution of macrovessels in BOLD fMRI, nevertheless the exact mechanism behind the practice needs further study.

References:

[1]Haacke E.M et al. Magn. Reson. Med. (52), 612-618, 2004.; [2]Reichenbach J.R. et al. J. of Computer Assisted Tomography 24(6), 949-957, 2000.; [3]Ogawa S et al. Proc. Natl. Acad. Sci. U.S.A., 9868-9872, 1990.