Fast Susceptibility Weighted Imaging: FSWI

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Introduction In the last years a new contrast mechanism has been introduced referred to as phase contrast or susceptibility weighted imaging (SWI) [1], showing in phase images a strong contrast between gray matter (GM) and white matter (WM). Particularly at high field strengths a higher GM/WM contrast is observable than that in the corresponding magnitude images. Several possibilities are being investigated to understand the source for this contrast, e.g. various iron concentrations in different tissues or more recently water-macromolecule exchange processes [2]. SWI experiments are typically performed with a gradient recalled echo (GRE) sequence leading to a measurement time around ten minutes for a complete volume. The acquired phase images are highly affected by B_0 fluctuations which have to be corrected. The use of phase array coils poses additional complications for the data combination, which are typically overcome by a computation-intensive 3D phase unwrapping. Here a method is presented to extract image phase, featuring a similar contrast as in SWI, acquired with a standard gradient-echo echo planar imaging (EPI) sequence without having to correct for phase wraps and is referred here as fast SWI (FSWI).

Theory In [3] a method was proposed to calculate susceptibility gradients in phase encode direction from the image phase of an echo planar image by calculating the effective echo time. This approach was extended recently to the readout direction as presented in [4]. Resulting gradient maps are exemplarily shown in Fig. 1 a) and b); they feature some anatomical details of the brain. These gradient maps can be integrated e.g. with a 'shape from shading' technique (e.g. [5]) in order to obtain the magnetic field which is, unfortunately, scaled in an unknown way. The integrated maps are dominated by the global B_0 fluctuations (as visible in Fig 1 c)), which have to be subtracted to make phase contrast visible. The integrated maps were scaled from 1 to -1 and were fitted with two-dimensional polynomials. The resulting polynomials were then subtracted from the original map in order to accent the anatomical structures.

Methods Six experiments (P0 to P5) were performed with different parallel imaging acceleration (PAT) factors in order to achieve high resolution echo planar images. All experiments were performed on a healthy volunteer with a standard EPI sequence on a 3T Tim TRIO (Siemens Medical Solutions, Erlangen, Germany) with a standard twelve channel head coil. Common parameters were: FOV: 22.4×22.4 cm, 20 slices, 32 acquisitions, TA = 2 min, the other parameters are listed under each image in Fig. 2. The image reconstruction was performed on the scanner with a GRAPPA reconstruction algorithm in order to keep the phase information for each channel. For all experiments the gradient maps of every acquisition were calculated, the blood vessels were identified in the images and replaced with an averaged value from the surrounding pixels. Thereafter gradient maps were integrated (one example is shown in Fig 1 c)) with the method proposed by [5], averaged, masked, fitted with polynomials of the 10^{th} order. The fit results were subtracted from the integrated B_0 maps to produce SWI-like images. These steps were performed offline in Matlab (The MathWorks, Inc., Natick, MA, USA). The brain mask was created with the Brain Extraction Tool from FMRIB (Oxford, UK). The vessels removal was performed in order to avoid strong differences of neighbouring pixels which would falsify the integration.

Results The resulting images of one slice are shown in Fig. 2. All images, except the one from the experiment P4 show a GM/WM contrast known from the traditional phase contrast images. P2, P3 and P5 show the highest contrast between GM and WM. P4 is highly affected by the noise. P2 and P5 show similar anatomical details. The computation time on a stock PC for the above described steps to create one FSWI image with matrix size 240×240 pixels and known brain mask amounts approximatively to 190s which is much faster than standard phase unwrapping algorithms.

Conclusion and Outlook A goal of this study was to evaluate the usability of high resolution EPI for SWI. An appropriate method has been described in order to obtain phase contrast images acquired with a standard EPI. The method has the advantages of rapid data acquisition and a fast computation. No phase wraps have to be unwrapped and no sequence modifications were necessary. Further developments are needed in order to improve the fitting of the global B_0 fluctuations and consequently increase GM/WM contrast. Geometric distortions may be corrected using field maps produced as an intermediate step of the FSWI reconstruction, once the problem of the unknown scaling of the maps is resolved.

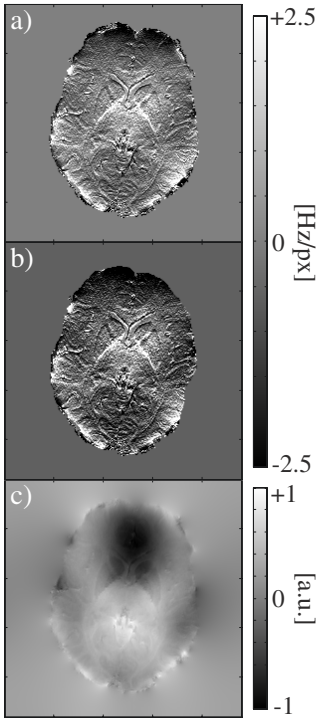
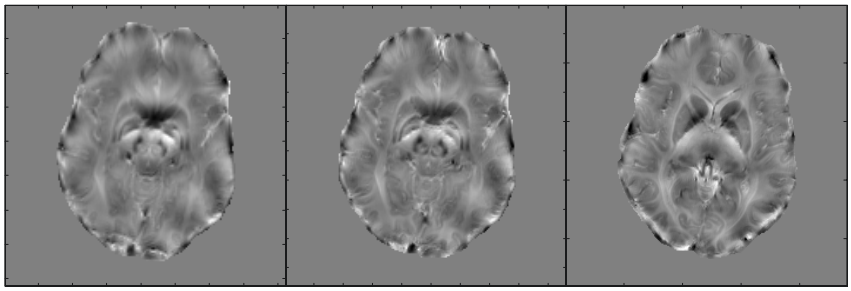


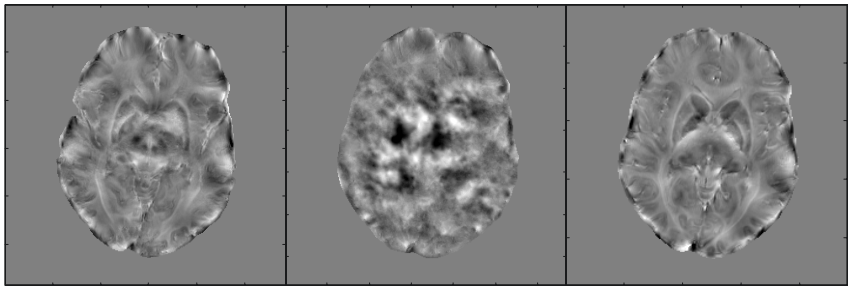
Fig. 1: a) and b): Gx and Gy Gradient maps from a healthy volunteer, respectively;
c): result after integration of the above shown gradient maps



P0: no PAT, TE = 40ms, matrix size=164×164 pixels, echo spacing time: 0.82ms

P1: PAT factor: 2, TE = 40ms, matrix size=192×192 pixels, echo spacing time: 0.93ms

P2: PAT factor: 2, TE = 40ms, matrix size=240×240 pixels, echo spacing time: 1.09ms



P3: PAT factor: 3, TE = 40ms, matrix size=292×292 pixels, echo spacing time: 1.3ms

P4: PAT factor: 4, TE = 40ms, matrix size=334×334 pixels, echo spacing time: 1.52ms

P5: PAT factor: 3, TE = 30ms, matrix size=240×240 pixels, echo spacing time: 0.99ms

Fig. 2: Resulting phase contrast images from the six experiments.

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