Simultaneous estimation of I₀, R₂*, and field map using a multi-echo spiral acquisition

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Abstract

INTRODUCTION

Recent multi-echo studies have shown an echotime (TE) dependence in components of the fMRI signal, with interest in using R₂* as a measure of functional activation [1,2]. However, macroscopic effects of R₂* and the field map cause degradations and distortions in single-shot gradient echo images. Correcting these distortions can lead to more accurate gradient-echo imaging in general, and more accurate R₂* maps for functional studies.

To account for interactions between R₂*, I₀, and field inhomogeneities, we performed a regularized nonlinear least-squares joint estimation of the I₀ image, R₂* map and field map based on modeling the signal equation. This approach was compared with standard estimation methods for R₂* (log-linear and nonlinear fitting) during a functional experiment.

METHODS

A multi-echo spiral pulse sequence with 4 echo times (TE=4.8/25.28/45.76/66.24ms, TR/FA/FOV=500ms/45/20cm, Matrix size=62, 400 time points) was implemented on a 3T GE Signa scanner. The first image was delayed by an additional 2.5 ms in order to form a standard field map. This field map was used as an initial estimate in our iterative algorithm and was also used to correct the time-series images for the standard method using a conjugate phase reconstruction [3,4].

We developed a cost function that models the signal equation with field inhomogeneities and R₂* taken into account. Our cost function depends on the current estimates of the field map, R₂* map, and image, so we alternate reconstructing the image using our current estimate of the R₂* and field maps and updating the R₂* and field maps using the current estimate of the image. We take advantage of the linearity of the image reconstruction problem and use the conjugate gradient method to find an estimate of the image using the data from all of the echoes. Gradient descent was used to update the field and R₂* maps.

RESULTS

A simulation object with R₂* and field inhomogeneity was used to compare the various estimation methods. Typical values for gray and white matter R₂* were used [5]. Figure 1 shows the simulation results. Errors in the field map resulted in overestimation of R₂* for the standard estimation schemes. The NRMSE over the object for R₂* was 31%, 20%, and 5% for the ln-linear, linear, and simultaneous estimation methods, respectively.

A finger-tapping task (20s off/20s on/5 repeats) was presented to one subject. Figure 2 shows task correlation results (using 240 images) for each method for one slice. The simultaneous estimation method has an increased amount of activation compared to the standard methods, without an appreciable increase of false positives outside the motor cortex.
DISCUSSION
Our regularized nonlinear least-squares joint estimation method shows increased accuracy in determining $R_2^*$, field map, and $I_0$ in the simulation study. The method uses the timing of the k-space readout and models the signal equation using current estimates of the parameters. This aided in accurate quantitation of tissue parameters and detection of BOLD $R_2^*$ modulation.

REFERENCES

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