EXTended Rosette ACquisition Technique (EXTRACT) : a dynamic R2* mapping method using extended rosette trajectory

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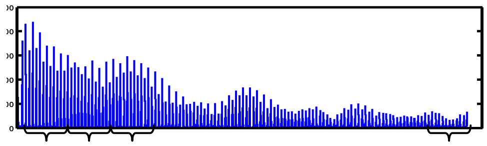
Introduction

Dynamic R2* mapping has been used in several MRI applications, such as functional imaging [1-4], and tissue identification by bolus tracking [5]. In functional imaging, R2* mapping has several advantages. It provides better functional contrast than BOLD imaging. The comparison between different subjects and scans is easier, because it is not dependent on the scan parameters such as TR and TE, or on baseline drift. [3] In addition, the separation of inflow effect from BOLD signal is possible [4]. However, conventional dynamic R2* mapping [1-4] relies on multiple gradient echo (2 ~ 8 echoes) imaging methods, suffering from either significantly increased data acquisition time, or/and motion artifact and physiological noise.

In this work, we propose the EXTended Rosette ACquisition Technique (EXTRACT), which can provide a short acquisition time of ~50ms, and dynamic estimates of T2*-weighted images, R2* maps and field inhomogeneity maps simultaneously.

To demonstrate the accuracy of the method, we performed a phantom study and compared EXTRACT to a mono-exponential fit of 6-echo spin warp images. We also present a functional study result from BOLD imaging and the proposed method.

Method



Formulation of segmented image reconstruction scheme: The MR signal S(t) with mono-exponential R2* decay can be modeled as a series of time-segmented data sets $S_i(t)$ (i=1…L)

$S_i(t) = \int M_i(\mathbf{x}) e^{-2\pi i \mathbf{k}(t)\cdot\mathbf{x}} d\mathbf{x}$, where $M_i(\mathbf{x}) = M_0(\mathbf{x}) e^{-R2^*(\mathbf{x})TE_i} e^{-i\omega(\mathbf{x})TE_i}$ and $TE_i \le t < TE_{i+1}$.

Since the individual reconstructions of M_i's from corresponding data segments $S_i(t)$'s would be highly underdetermined, we used a temporal smoothness constraint between M_i's in addition to spatial smoothness constraints. The reconstruction is done by minimizing the following cost function over $M_1, M_2, \ldots, M_L$ using the conjugate gradient method;

$\Phi = \sum_{i=1}^{L} \|S_i - A_i(\hat{\omega})M_i\|^2 + \sum_{i=1}^{L} \beta_{1i}\|CM_i\|^2 + \sum_{i=1}^{L-1} \beta_{2i}\left\| e^{-\hat{R}_2^*(TE_{i+1}-TE_i)} M_i - M_{i+1}\right\|^2$, where the i'th time-segmented MR system matrix is

$[A_i]_{pq} = e^{-2\pi i \mathbf{k}(t_p+TE_i)\cdot\mathbf{x}_q} e^{-i\hat{\omega}(\mathbf{x}_q)(t_p+TE_i)}$, C is the spatial regularization matrix as in [6], and β_{1i}, β_{2i} are regularization parameters.

The proposed method (EXTRACT):

1. Reconstruct preliminary images $M_1, M_2 \ldots, M_L$ using the reconstruction method described above, using $\hat{\omega} = 0$, and $\hat{R}_2^* = 0$.
2. Estimate preliminary R2* map ($\hat{R}_2^*(\mathbf{x})$) and field inhomogeneity map ($\hat{\omega}(\mathbf{x})$) by log-linear fitting the magnitudes and linear fitting the unwrapped phases of the M_i's respectively.
3. Reconstruct the M_i's again using the R2* map and field map from 2.
4. Estimate the final R2* map and field map from exponential fit of M_i's from 3.
5. Repeat 3 and 4 if necessary

Experiment

Phantom study: Three 20oz. bottles of CuSO4 solution with different concentration were used as R2* phantoms. Six gradient echo spin warp images were acquired using a GE 3T scanner (TEs at 10ms, 15ms, 20ms, 25ms, 30ms, 35ms, 256x256, TR = 0.5s, FOV=20cm) and R2* maps were calculated from exponential fitting of the magnitude images. The extended rosette data was acquired (TE at 5ms, ω_{osc}=1.1kHz, ω_{rot}=34.6Hz, acquisition length = 58.1 ms, TR = 2s), and L=32 was used in the reconstruction.

Functional study: A human subject was given a finger tapping task (20s off, 20s on, 4 cycles) with a visual stimulation. For BOLD imaging, a spiral trajectory was used (TE at 30ms, TR = 2s, slice thickness = 4mm, in-plane resol. 3.125mm, 20slices). For EXTRACT, the same extended rosette trajectory and L were used as in the phantom study with the same spatial resolution as spiral imaging. From the latter half of the extended rosette data, we derived T2*-weighted (BOLD) images, which had TE approximately at 35ms. The activation maps were calculated by correlating with a reference waveform.

Results and Discussion

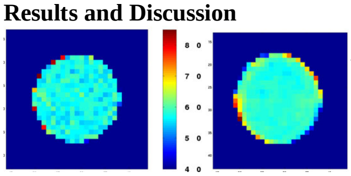


Fig 1 Fig 2

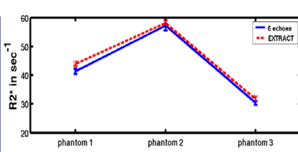


Fig 3

Fig 4 Fig 5 Fig 6

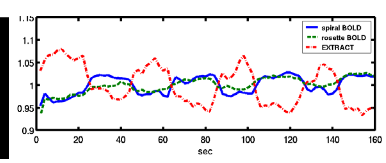


Fig 7

Fig 1 and 2 show the estimated R2* map (matched resolution and zoomed in) from the multi echo method and EXTRACT respectively. Fig 3 shows the mean and error bars over an ROI of each phantom. Fig 4, 5, and 6 show the activation maps from spiral BOLD, rosette BOLD, and the R2* map from EXTRACT. Fig 7 shows the normalized time course of each method. The proposed method produced a lower noise in R2* map (in ROI) than the multiecho method, since it includes spatial regularization for the subimage reconstruction. The number of segments (L) was chosen to be big enough to have negligible signal dephasing during each time segment, and small enough to result in acceptable subimage quality. For the functional study, EXTRACT required a high order shim, since the rosette trajectory is highly susceptible to intra-voxel dephasing due to the field map gradient.

Summary

We demonstrated that EXTRACT could be used for dynamic R2* estimation with a relatively short scan time and reasonable reconstruction time. Through a phantom study and functional study, we also showed that the method can provide highly accurate estimates of R2*, and detect functional changes of R2* in human brain.

References

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