Spinal cord functional MRI: gradient echo versus spin echo

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Introduction

Spinal cord fMRI may be a valuable diagnostic tool to provide new insights in unresolved cord pathologies and to assess cord viability in terms of tissue perfusion. Although functional MRI of the spinal cord has now been demonstrated by a number of independent research groups[1-7], high quality imaging remains problematic in contrast to the brain. Spinal cord image quality is strongly hampered by cord motion, magnetic field inhomogeneities, and the small cross-sectional dimensions[8,9].

Thus far it is unclear whether gradient echo (GE) or spin echo (SE) imaging is the most suitable technique. Theoretically, GE is expected to be more sensitive to the blood oxygen level dependent effect[10], but SE might be more accurate to the detailed localization of neuronal activity as it is less sensitive to extravascular field inhomogeneities from large veins. Also SE is in general less sensitive to magnetic susceptibility artifacts and consequently provides better image quality. The objective of this study was to compare GE and SE fMRI of the cervical spinal cord and to test the reproducibility at 3 Tesla field strength.

Methods

Optimization. For maximal signal response to T_2 relaxation time changes the echo time should ideally be set to $TE = T_2$. However, this setting provides sub optimal signal-to-noise ratio (SNR) and strong susceptibility artifacts. To obtain the combination of optimal signal sensitivity and SNR, a mathematical merit function M was defined as the product of the MRI signal (S) and the signal sensitivity to T_2 changes (dS/dT_2)

$$M(TE) = S \cdot \frac{dS}{dT_2} = \frac{S_0^{\,2}}{T_2^{\,2}} TE \exp(-2\frac{TE}{T_2}),$$

where S_0 is proportional to the proton density (Fig.1). For gradient echo imaging T_2 has to be replaced by T_2*. To determine the dependency of the merit function on the echo time, T_2 and T_2* relaxation times were determined using spin echo and gradient echo measurements, respectively, in the cervical spinal cord of healthy volunteers. The measured values were $T_2 = 70 \pm 7$ ms (median ± SEM) (n = 3) and $T_2^* = 46 \pm 2$ ms (n = 2). Merit functions are maximal at $TE = ½T_2 = 35$ ms for SE and $½T_2^* = 23$ ms for GE imaging (fig.1). These echo times were approximated in the subsequent fMRI.

fMRI protocol. Healthy volunteers underwent GE (n = 10) and SE (n = 8) fMRI of the cervical spinal cord on a 3T MRI system (Philips Achieva). A phased-array receive spine coil was used with the appropriate coil elements selected for the vertebral range C1-T2. The activation paradigm comprised the alternation of unilateral finger motion and rest. Motion of left and right hand fingers took place in separate sessions. GE acquisition: *TE/TR* 20/486 ms, EPI read out with segmentation factor 15; SE acquisition: *TE/TR* 35/5890 ms, TSE read out with *k*-space segmentation factor 68. Common parameters: matrix of 256x128, field of view 250x125 mm, flip angle 90°, and eight contiguous 1.4 mm thick sagittal slices[11]. Shimming volume was positioned over the cord tissue of interest. Flow artifacts were reduced by using flow compensating gradients in (feet-head) readout direction. To reduce artifacts due to breathing or swallowing a regional presaturation slab was positioned parallel and anterior to the cervical spine.

Data analysis. Rigid body realignment was applied to correct for motion in the dynamic image series. Because of the modest image quality, especially in GE imaging, smoothing was applied to increase SNR of functional images. To avoid signal mixture of different tissues the depicted cord was straightened and spatially smoothed using a one-dimensional Gaussian kernel (2.5 voxels). FMRI data were analyzed by linear regression of a standard hemodynamic response function. Voxels with a significant signal amplitude (threshold t-value ≥ 2) were assumed to represent activated tissue. FMRI signal was evaluated with respect to the spatial distribution of activation and percentage signal change relative to the baseline signal. According to neurological anatomy, spinal cord segments corresponding to the vertebral levels C5-T1 should be activated during finger motion.

Reproducibility. Three subjects underwent the fMRI exams twice on separate days. From these measurements the within-subject (σ^2_{ws}) and between-subject (σ^2_{bs}) variances were calculated from the fMRI percentage signal changes at the vertebral level range C5-T1. The reproducibility was expressed in terms of the intraclass correlation coefficient (*ICC*) which is defined as $ICC = \sigma^2_{bs} / (\sigma^2_{ws} + \sigma^2_{bs})$. The *ICC* may range between 0 and 1 and should ideally be as high as possible. Also the repeatability coefficient (*RC*) was used to indicate for the ability to detect biological differences. *RC* is defined by $RC = 1.96 \cdot \sqrt{2} \cdot \sigma_{ws}$.

Results

Signal changes. Subjects averaged fMRI signal change time-courses are provided in fig.2. Percentage signal changes were 10.4 ± 0.4 % (mean ± SEM) in GE and 5.2 ± 0.3 % in SE fMRI. For GE signal changes were maximal at levels C5-T1 (fig. 3a). SE measurements showed no distinct location with maximal activation (fig. 3b). Neither SE nor GE imaging provided lateralized activation to the unilateral finger motion exercises. Percentage signal change and number of activated voxels were approximately twice as high for GE than for SE fMRI. Signal changes for SE imaging were observed in the cord but also frequently outside the cord (cerebrospinal fluid space and spine), whereas for GE imaging the signal changes were found mainly inside the cord region.

Reproducibility. For GE (*ICC* = 0.79, *RC* = 2.3%) imaging the reproducibility of the signal changes was higher than for SE (*ICC* = 0.20, *RC* = 3.0%) imaging.

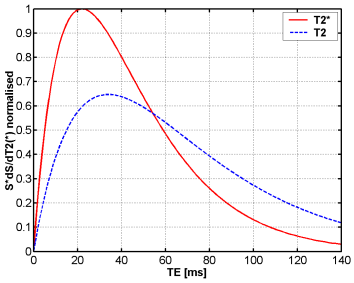

Fig.1 GE (red) and SE (blue) merit functions relative to maximum for GE imaging.

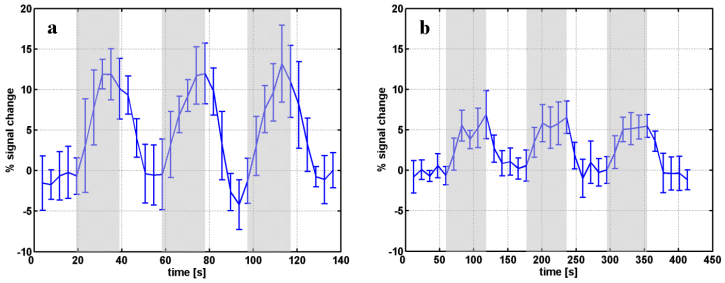

Fig.2 Subjects averaged time-series of activated voxels, at vertebral levels C5-T1 for (a) GE and (b) SE fMRI. Errorbars indicate standard deviation. Shaded zones indicate finger motion periods.

Conclusion

Spin echo and gradient echo pulse sequences for cervical spinal cord fMRI were optimized for signal sensitivity and signal-to-noise characteristics and evaluated for finger motion tasks at 3T field strength. Gradient echo based fMRI appeared more signal sensitive, location-specific and reproducible than spin echo imaging.

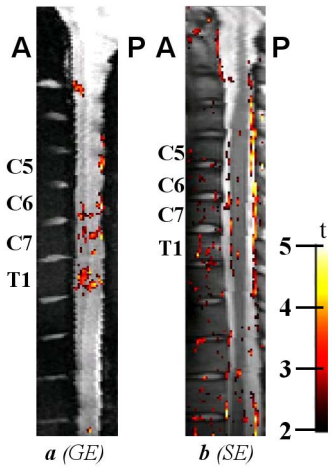

Fig.3 Distribution of activation by t-value overlays, for GE (a) and SE (b) fMRI.

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