Cerebrospinal Fluid (CSF) Flow Suppressed Spinal Cord Functional MRI Using Multi-slice DANTE-EPI

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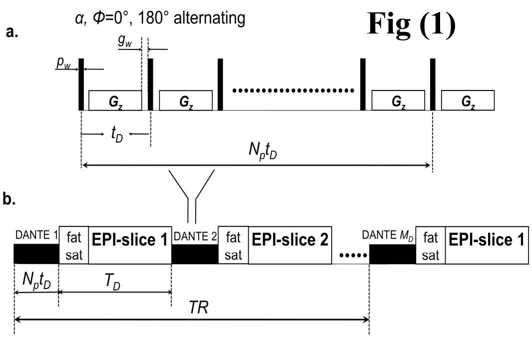
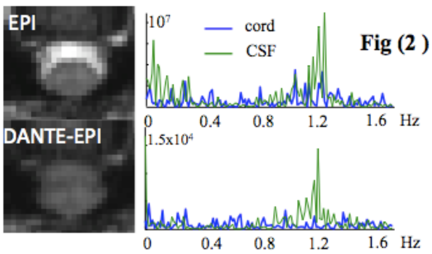
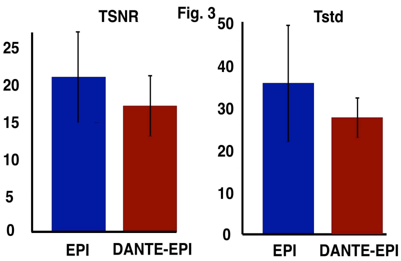
Background: The quality of blood oxygenation level dependent (BOLD) contrast in the spinal cord can be seriously compromised by flow related instabilities caused by CSF pulsations and false activation caused by CSF contamination (partial volume effect) [1]. Problems can be partially solved by employing a presaturation slab [2]. We have previously demonstrated that during application of DANTE pulse trains (a rapid series of low flip angle RF pulses interspersed with gradients), longitudinal magnetization of flowing spins is largely (or fully) attenuated, in contrast to static tissue, whose longitudinal magnetization is mostly preserved. We have also shown that DANTE may be adapted as a fluid suppression module for multi-interleaved slice acquisition [3]. Here, we propose to a method that employs a interleaved DANTE preparation for CSF flow suppression in multi-slice spinal cord fMRI and compare its performance against conventional spinal cord EPI fMRI.

Methods: The proposed DANTE-EPI imaging sequence is shown in Fig 1, indicating both the DANTE preparation module itself, as well as its integration into a multislice interleaved EPI readout method. The number of pulses applied in the individual DANTE module N_p=1000 and 256 for 3 slices and 9 slices acquisition, respectively. The time between low flip angle pulses is t_D=0.5ms and flip angle α is 3°. T_D in Fig. 1b represents the inter-DANTE module delay time reserved for the readout module. The performance of DANTE-EPI and conventional EPI methods was compared using resting state fMRI scans (300ms and 2s TR) and using a finger tapping motor task. Resting state data were evaluated using (1) a hand-drawn cord mask and signal variance maps, and (2) power spectra of resting time series. Three healthy volunteers were trained to perform finger tapping at a frequency of approximately 1 Hz with either their right or left hand. A block design was used with seven 30 s rest and six 30 s active blocks. Three (at the C6 level) or nine (covering C5 to C8) cervical axial slices were acquired on a 3T Siemens Verio scanner (4 channel neck coil) with the following parameters: TE/TR=31/2000ms, FA=90°, GRAPPA (factor=2), phase encoding (P→A), resolution 1.33x1.33 mm in-plane (96x96), 4mm slice thickness with 100% gap, receiver bandwidth=1086Hz/pix. Physiological data were acquired with a pulse oximeter and respiratory bellows. Each slice was motion corrected in 2D using FLIRT (part of FSL). Subsequently, data were spatially smoothed (3mm FWHM), high-pass temporal filtered (90s), and activity assessed using slice specific physiological noise regressors within the general linear model (FEAT, part of FSL) [4]. Activity is reported for p<0.01 (uncorrected). In both experiments the EPI parameters were identical, except that for conventional EPI acquisitions, the DANTE flip angle (FA) is equal to zero.

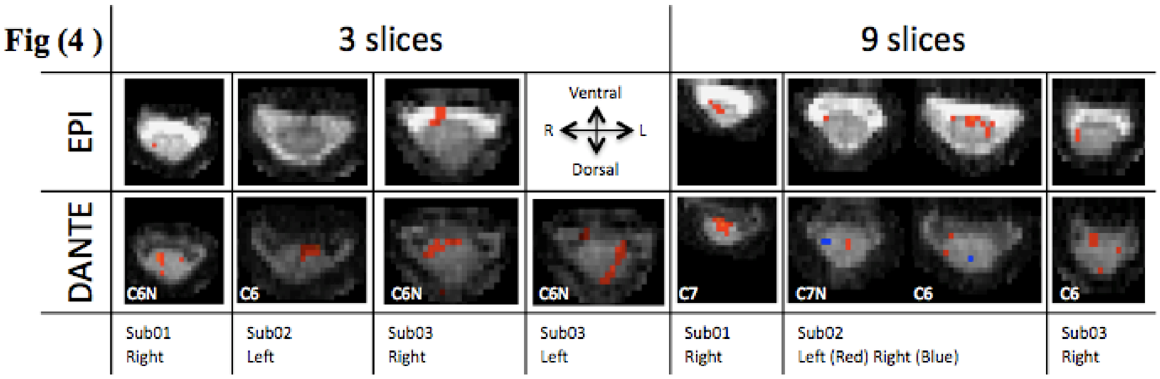


Results: Single slice resting state data (TR=300ms) and power spectra of the time courses in the CSF and the cord areas from both EPI and DANTE-EPI are shown in Fig 2. CSF is seen as a bright area surrounding the dark spinal cord in the conventional EPI data, and is effectively suppressed in the DANTE-EPI data. The dominant noise source in both CSF and cord for conventional EPI was cardiac (~1.2Hz). However cardiac effects within the spinal cord were minimal after CSF signal attenuation with DANTE-EPI. Note that with flow suppression the static signal intensity is also reduced (decreasing ~20% of the spinal cord signal for DANTE-EPI). As such, the temporal SNR for DANTE-EPI was decreased inside the cord, although the variance also decreased (Fig 3). Activation maps for the motor task for both protocols are shown in Fig 4.





For the three slice-interleaved runs, DANTE-EPI outperformed the standard EPI sequence. In particular, activity for DANTE-EPI was primarily located in the ventral cord ipsilateral to the side of finger movement, which agrees with the known anatomical location of motor neurons within the spinal cord. With conventional EPI, activity was either absent or located primary within the CSF space (see “3 slices” Sub3). For the nine slice-interleaved runs, similar patterns of activation were observed for sub01 and sub03, but not for the sub02 – with more diffuse activity located throughout the cord (particularly for DANTE-EPI acquisition).



Conclusions: In this study, a novel DANTE-EPI technique for CSF flow suppressed spinal cord functional MRI was implemented. Compared to a conventional EPI spinal cord sequence, the temporal variance within the spinal cord was decreased. Improved activation patterns were observed in three subjects using a block-design finger tapping task. This is an ongoing research project and mixed effect group analysis with different types of stimuli will be assessed in further studies.

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