7D velocity phase imaging with zoomed simultaneous multi-slice EPI reveals respiration driven motion in brain and CSF

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Introduction MR studies to date show cardiac driven pulsations of CSF. However, mechanisms of CSF circulation are incompletely understood compared to blood and lymphatic circulations and forces driving interstitial fluid circulation within brain parenchyma are currently unknown. In this work, we developed a fast real-time velocity MR imaging technique for simultaneously measuring CSF and brain velocities. This technique is applied to healthy subject, leading to findings of breathing dependent CSF and brain pulsations in addition to their known cardiac pulsations[1].

Methods A dual-band saturation pulse is applied with a simultaneous multi-slice (multiband) EPI sequence for outer volume suppression for zoomed velocity phase contrast imaging. The parameters are as below: TR=78ms, TE=32ms; in-plane undersampling factor =2; partial Fourier factor=6/8; spatial resolution=1.5x1.5mm^2; slice thickness=3mm; matrix size: 128x80; 18 slices. The 30 seconds of real-time scan was performed for each velocity direction. The velocity phase shifts were encoded with bipolar gradient pulse (venc=5cm/s) using phase subtraction sliding between TRs in which the bipolar pulse had alternating polarity. Simultaneous multi-slice EPI encoded 3 slices with multiband factor=3; blipped-CAIPI controlled aliasing 1/3 FOV shift. A slice-grappa algorithm with kernel size of 3 was used to separate the images. For controlled comparison, a respiratory sensor band at level of diaphragm was used. The 30 sec of real-time imaging was repeated to obtain 3 different velocity encoded directions, Vx, Vy, Vz and repeated 6 times for 18 slice in a 10 minute acquisition to measure brain and CSF velocity. Three normal subjects were imaged on a 3T scanner using a 32 channel receiver coil.

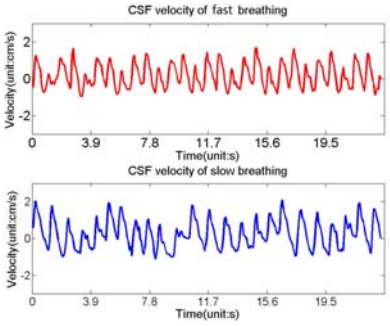

Fig. 1 Comparison of rapid breathing (top, red) and slow breathing (bottom, blue) on CSF velocity waveform (Vz) at level through the foramen Monroe.

Results CSF velocity changes during slow and rapid breathing were readily identifiable as modulation in the velocity waveform of the higher frequency cardiac waveform, Fig. 1. With a near constant breathing rate, the 7D image data (3D spatial, 3D velocity, 1D temporal) of brain and CSF shown in Fig. 2 was remarkable for its respiratory modulated waveforms seen in longer 30 second tracings correlated with external belt measure of breathing rate. To separate the cardiac and respiratory waveforms, the data low pass filter had a cut-off frequency of .5 hz, and the bandpass filter had a cutoff window of 1-1.2 hz. The aqueduct has greatest velocity through slice (Vz) direction. The lateral sulcus CSF velocity is similar magnitude in 3 directions. The region of brain parenchyma has lower velocity magnitude than the CSF spaces, nevertheless both cardiac and respiratory frequencies are present. Breathing waveforms simultaneously measured during MR scanning with respiratory belt tracings (Fig.2, far right) are shown. Similar velocity waveform distributions were found in all subjects.

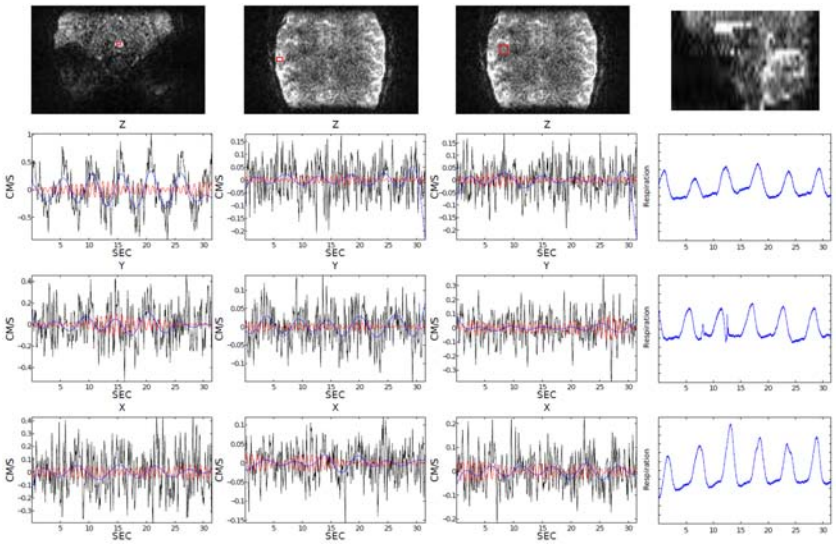

Fig. 2 7D velocity-spatial-temporal acquisition. Velocity waveforms are recorded at all points in the 3D spatial map, here measured in regions in red boxes shown in top row (left) aqueduct, (middle left) sulcus, (middle right) brain parenchyma, (right) sagittal view of data with below (blue) respiratory tracings from thoracic belt monitor recorded synchronous with brain parenchyma waveforms. The cardiac waveforms (red) and respiratory waveforms (blue) are created from filtering time series data.

Discussion With this highly efficient data acquisition strategy for real-time velocity imaging, accelerated to reduce total acquisition time and zoomed for higher resolution, it is possible to quantify brain and CSF motion modulated by both cardiac and respiration driving forces. While signal changes have been reported to be correlated to breathing, to our knowledge there have been no prior reported measurements of respiration driven velocity waveforms in brain or CSF. In this regard, it seems likely that clinically used cardiac-gated GRE cine-velocity imaging (3) of CSF will have systematic errors from respiratory velocity variations not accounted for during a several minute long acquisition followed by retrospective sorting signal into cardiac phase alone. Improvement in temporal resolution of the 7D scan down to 50 ms using a smaller FOV to shorten echo train length and by performing a correction phase map to allow a single polarity bipolar pulse to reduce temporal resolution from 2 TR to single TR have also been implemented. Relevent to our findings of pulsatility in the brain, recent research shows that CSF circulation may occur from periarterial spaces into the parenchyma may be an important clearance mechanism potentially playing an important role in neurodegenerative disease[3]. The presented technique of real-time velocity imaging may be used to study CSF fluid mechanics and applied in studies of hydrocephalus and neurodegenerative disease.

References: (1) Feinberg DA, Radiology 1987, (2) Enzman D, Radiology, 1991 (3) Iliff JJ et al, Sci Transl Med 15 August 2012.
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