Velocity phase imaging with simultaneous multi-slice EPI reveals respiration driven motion in spinal CSF.

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Introduction

ECG-gated phase contrast (PC) GRE imaging is currently widely used for fluid velocity imaging (1). However, from studies of EPI signal intensity variation (2) and our recent studies with EPI real time velocity imaging (3), CSF in brain is not only modulated by cardiac pulsation but also by respiratory motion which cannot be detected with PC GRE imaging (3). Since CSF spaces in the head are continuous with CSF in the spinal canal and current spine velocity in literature is acquired with PC GRE imaging, here we propose to use simultaneous multi-slice (SMS) velocity imaging to investigate spinal CSF motion.

Method

Subjects were scanned on a 3T Siemens scanner using a 32-channel head coil. Three velocity images, widely spaces in axial orientation, were simultaneously scanned in real time. The velocity imaging parameters were: TR=78 ms, TE=40ms, in-plane under-sampling factor=2, matrix size=128x80, slice thickness=5mm; SMS-MB factor=3, FOV shift factor=FOV/3. VENC=2.5 cm/s. A slice-grappa algorithm was used to extract the multiple slices followed by GRAPPA algorithm for the in-plane under-sampling processing. Alternative +/- VENC bipolar gradient pulses were used for adjacent TRs. The phase difference of the images from alternate TRs is proportional to the CSF velocity. Velocity images are acquired from different regions to investigate the velocity distribution in spine. Three subjects were instructed to breathe at a steady rate during imaging. In one subject, velocity images were also collected from the head in the same session for comparison. For head images, a skewed saturation pulse was applied for outer volume suppressed (OVS) zoomed SMS EPI imaging. For all sessions, T2 weighted anatomical images were also collected for ROI identification and display.

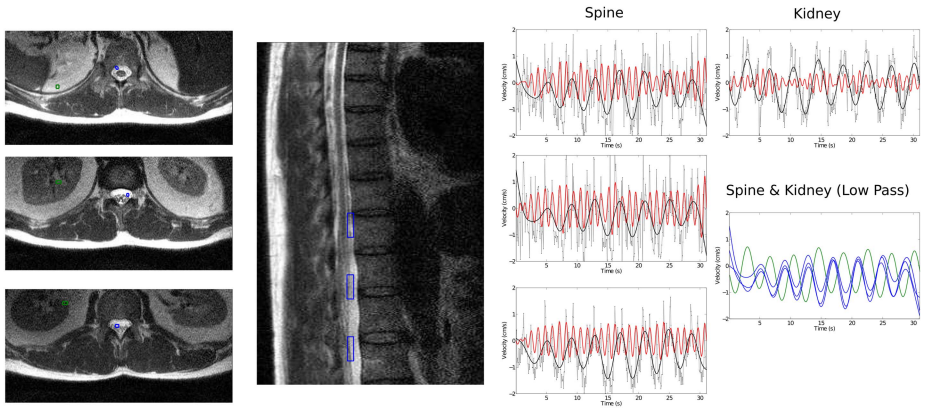

Figure 1: Velocity time series collected from spinal CSF ROIs (blue) and one non-spinal ROI (green). Band-passing of the time series from the spinal ROIs indicates modulation of the velocity by respiratory (black curve) and cardiac (red curve) activity. The non-spine time series shows modulation at the respiratory frequency that is opposite in phase to the spinal ROIs.

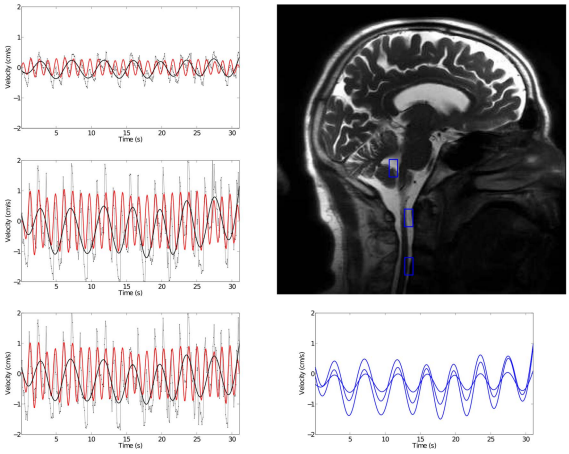

Figure 2: CSF velocity time-series from the head. Same display conventions as for Fig 1. ROIs at 3 different levels show both respiratory and cardiac modulation (at differing amplitudes), the phase of which matches across levels.

Results

CSF velocity changes in the spine were modulated at the same frequency as the subjects breathing (Figure 1). The velocity in an ROI placed on the subjects kidney which was displaced down by the diaphragm was also modulated at the frequency of the respiration, but the phase of the modulation was opposite in phase to that in the spinal CSF ROIs. CSF velocities measured in the head later in the same session showed the same pattern as the spinal ROIs: respiratory and cardiac modulation, with the phase of the respiratory modulation being consistent across the three regions measured simultaneously.

Discussion

With current real-time velocity imaging, CSF velocity can be monitored to find that CSF motion in the spine is not only modulated by cardiac motion but also by respiratory motion. This result is similar to that found in brain CSF, as shown here and in earlier studies (2,3). Using an SMS-EPI velocity sequence, we can monitor different slices in spine or head simultaneously, and from our data we can see that there is little to no phase offset for the velocity curves of different slices. Comparing this modulation to that seen in the kidney which is displaced downward by the diaphragm during inhaling, we see this modulation is of the same frequency but with opposite phase, indicating that the direct coupling of the CSF motion in the spinal canal to respiratory motion, similar to how CSF velocity and brain motion appeared coupled by cardiac pulsations (4).

References

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