# Multiband Velocity EPI

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**Introduction** Multiplexed EPI is an echo planar imaging technique that acquires several images simultaneously by incorporating the accelerations of both simultaneous echo refocusing (SIR) and multiband (MB) techniques [1]. Previously, the sequence was used for faster diffusion imaging by adding diffusion encoding gradient pulses. In this work, a faster multi-slice imaging sequence is proposed for velocity imaging. For preliminary feasibility assessment, here only the multiband technique is applied and evaluated in time-series velocity imaging with multiple slice planes acquired simultaneously.

**Methods** The pulse sequence, Fig. 1 incorporates the MB excitation pulse and a bipolar gradient pulse to simultaneously encode velocity phase shifts in all slices. VENC=5 cm/s was used for the CSF and brain motion experiment and VENC=60-80 cm/s for the artery experiment. Multiband rf pulse factor was 3 or 6, for simultaneous exciting a corresponding number of slices. A set of single-band (normal) EPI images VENC=0 were acquired at the beginning to be used as sensitivity maps for multiband image extraction and reconstruction, followed by a multiband VENC=0 acquisition, followed by a time-series of multiband non-zero VENC acquisitions. The phase images of each coil were combined using equation: $\phi = \angle\left(\frac{\sum_{icoil=1}^{Nc} M_{icoil}\exp(i\phi_{icoil})}{\sum_{icoil=1}^{Nc} M_{icoil}}\right)$ where $M_{icoil}$ and $\phi_{icoil}$ are the magnitude and phase of the image of each coil, and *Nc* is the total number of coils [2]. The constrained phase difference between VENC of non-zero and zero were used to generate the phase images and velocity curve were further corrected using phase from stationary fat. The scanner was a 3T (Siemens Trio) with a 32 channel receiver coil. The acquisition parameters are: matrix 96 × 96, in-plane resolution 2.0mm x 2.0mm, slice thickness=3mm, TR=100ms, TE=35-40 ms, flip angle 16°, partial Fourier factor=6/8, excitation multiband sinc pulse duration= 5.12 ms, no phase encoding (PE) undersampling. FOV/3 control aliasing image shift [3] is applied with modulated Gs blipped pulses between echo readouts to improve the image reconstruction, and slice-grappa algorithm is applied to do the reconstruction with kernel size=5.

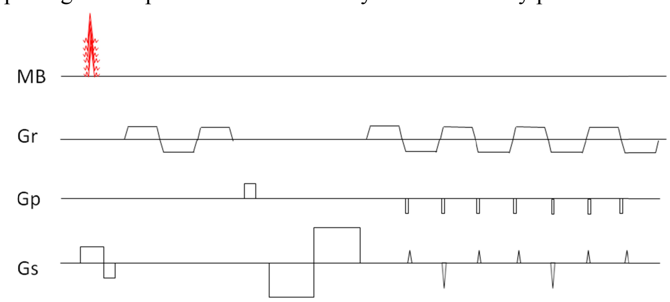


Figure 1

**Results** The results show the ability to simultaneously measure velocity in 3D regions covering the brain and CSF spaces and a six fold reduction in scan time compared to conventional EPI. Figure 2 shows one set of 6 phase and magnitude images recorded simultaneously in every 100ms TR, hence there were 55 sets of 6 images, at consecutive time points measured in 5.5 seconds. Figure 3 shows velocity vs time curves from ROIs drawn on images in CSF and brain regions recorded simultaneously at 10 frames per second with no cardiac gating. *The brain motion results:* b1- top slice (s1)/centrum semiovale, b2- s2/thalamus, b3- s4/midbrain, b4- s5, pons. Note increased velocity in lower brain regions, as previously reported [4-5]. *The CSF results*: csf1- lateral ventricle (vent) above foramen of Monroe, csf2- post. horn lateral vent. csf3- third vent , csf4-forth vent., csf5- cerebellarpontine cistern, csf6- cisterna magna. Fig. 4 shows left internal carotid artery (ICA) velocity - note in these preliminary results the baseline zero velocity is incorrect due to calibration errors and aliasing.

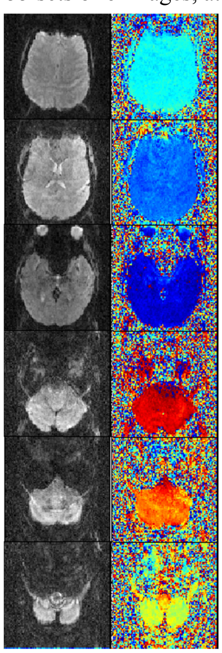

Figure 2

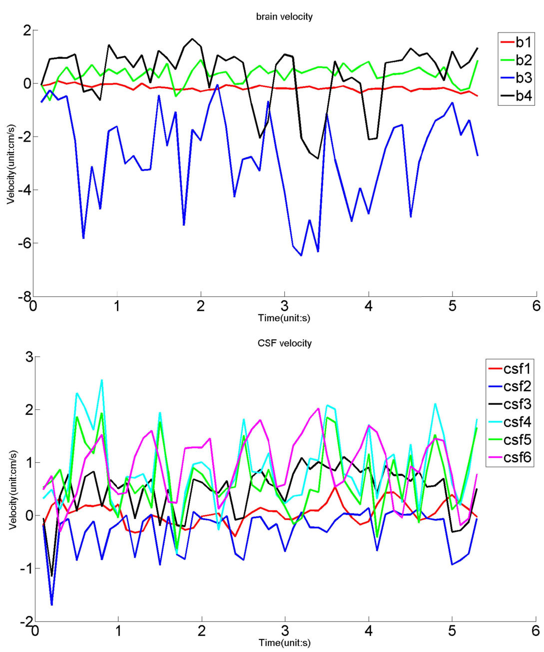


Figure 3

**Discussion**: We present a new approach to 3D velocity imaging which can be extended to acquire more slices simultaneously in real time acquisitions. Of interest, the pulsatility variations observed in the CSF and brain velocity curves represent physiologic variations given these images are not comprised of time segmented or temporally averaged data but are measured at 100ms frame rate. Possible artifactual phase drifts from off resonance changes, could be normalized using +/- VENC acquisitions in alternate frames for "phase contrast" subtraction at expense of temporal blurring between two frames. These are preliminary results and therefore substantial improvements should be possible with optimizations of flip angle, spatial resolution, higher frame rates, velocity calibrations, phase unwrapping, etc. Spatial resolution can be increased with longer echo trains and velocity encoding on all 3 gradient axes can be implemented for 3 vector components. With further development, 4-6 times more slices in the single-shot sequence may be possible allowing for whole brain coverage [1, 6]. In conclusion, a new technique of real-time velocity imaging is presented using multiband EPI acquisitions that simultaneously measures velocity in multiple slices and gave a six fold reduction in scan time of 4D velocity imaging.

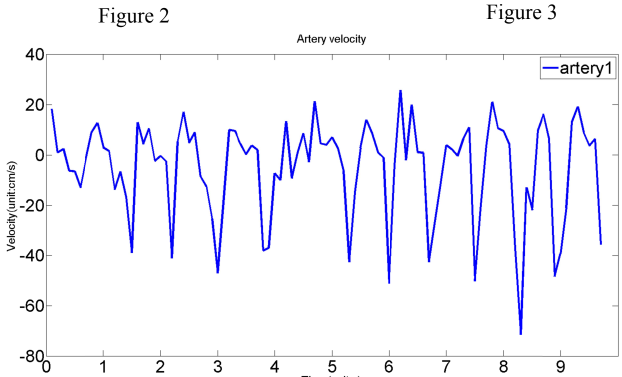


Figure 4

**References:** [1] Feinberg et al, Plos One 5, e15710 2010 [2] Hammond et al, NeuroImage 39(4) 1682-92, 2008 [3] Setsompop et al MRM 2011 *in press* [4] Feinberg et al, Radiology 163, 793-799, 1987, [5] Poncelet et al, Radiology 185, 645-651, 1992 [6] Chen L et al, *ISMRM* 2012

**Acknowledgement:** NIH R44 NS073417