

# Imaging High-Speed Jets Using Rapid Ungated Fourier Velocity Encoding

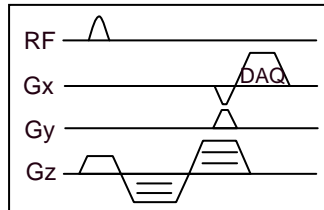
H. Z. Dong<sup>1</sup>, B. S. Hu<sup>1,2</sup>, J. M. Santos<sup>1</sup>, and D. G. Nishimura<sup>1</sup>

<sup>1</sup>Electrical Engineering, Stanford University, Stanford, CA, United States, <sup>2</sup>Cardiology, Palo Alto Medical Foundation, Palo Alto, CA, United States

**Introduction:** Accurate quantitation of the peak arterial jet velocity is crucial in assessing the severity of cardiovascular disease. The current “gold standard”, Doppler ultrasound, is highly sensitive to beam position and Doppler angle. Fourier velocity encoding (FVE) resolves the full velocity spectrum [1], but conventional gated methods [2-4] do not work well during arrhythmia and require long scan times. MR Doppler [5] gives good velocity distributions along a cylinder, but its long readout can cause signal degradation during highly accelerative flow. In this work, we developed an ungated FVE technique for imaging jet velocities that is fast and simple to apply. Through continuous velocity encoding and k-space data averaging, the sequence produces an accurate time-averaged velocity spectrum in just a few seconds.

**Methods:** Gated FVE gives time-resolved velocity profiles by acquiring predetermined velocity encodes for each cardiac cycle. Ungated FVE can provide time-averaged velocity spectra if each velocity encode captures enough of the cardiac cycle. This can be accomplished by acquiring k-space data repeatedly and averaging them. Because the time dimension is not required to quantify peak velocity, the ungated method potentially provides an easier and faster approach.

The proposed method is composed of FVE in the slice-select direction and in-plane readout (Fig. 1). To maximize the amount of averaging per unit time, the sequence was made compact by using a brief Gaussian RF and combining bipolar velocity encodes with slice-select refocusing lobe. Because images were projections in y, Gy phase twists were applied to reduce static tissue signals and improve dynamic range. A short readout gradient was used to resolve between different vessels, although it is not necessary for detecting the presence of jets in the excited slice. Velocity encodes were acquired in a sequential order.



**Figure 1.** Ungated FVE pulse sequence.

Scans were conducted on a 1.5T GE Signa scanner (40 mT/m, 150 mT/m/ms), and used a 3-inch surface receive coil. Pulsatile flow through a nozzle was imaged to study the number of averages needed to obtain a complete velocity spectrum. In vivo scans were performed on the common carotid artery and the aorta at the level of the pulmonary arch of healthy volunteers. k-Space data were windowed using a Tukey function to reduce Gibbs ringing. Results were compared to Doppler ultrasound. Scan parameters are summarized in the following table:

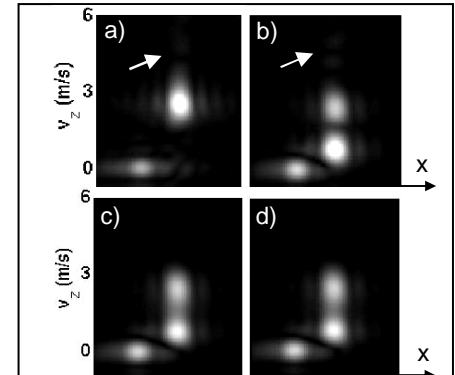
	TR	Velocity FOV	Velocity Res.	Spatial FOV	Spatial Res.	Phase Twist	No. Avg.	Scan Time
Phantom	5.0 ms	12 m/s	37.5 cm/s	20 cm	6.25 mm	None	1-30	0.3-4.9 s
Carotid	6.9 ms	2 m/s	6.25 cm/s	20 cm	6.25 mm	40 mm/cycle	16	3.7 s
Aorta	6.1 ms	4 m/s	12.5 cm/s	20 cm	6.25 mm	40 mm/cycle	16	3.2 s

**Results and Discussion:** Figure 2 presents phantom study results. After a few averages, most of the flow tube’s velocity spectrum became visible, but ghosting artifacts still lingered at high velocities. As the number of averages increased, the spectrum stabilized and showed a clear peak at 3.3 m/s. The peak carotid artery velocities obtained with the ungated FVE method and Doppler ultrasound were consistently 85 cm/s (Fig. 3). Ungated FVE further measured jugular vein and vertebral artery peak velocities to be 45 cm/s and 40 cm/s. In the aorta, the peak velocity measured using ungated FVE was 150 cm/s, which was verified using Doppler ultrasound (Fig. 4). Also shown are the velocity spectra of the pulmonary arch and superior vena cava, whose peaks were 65 cm/s and 60 cm/s. Because of averaging, motion artifacts were largely not seen.

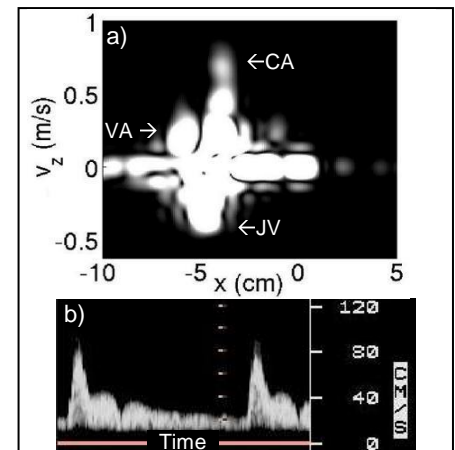
**Conclusion:** Ungated FVE with k-space averaging is a promising method for imaging high-speed jets. It gives accurate measurements, is fast and easy to apply, and is robust to motion artifacts. In addition, it provides the flow spectra of multiple vessels in one image.

## References:

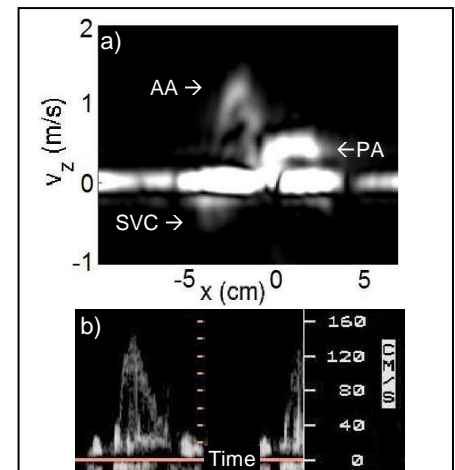
- [1] Moran P, JMR, 1:197, 1982.
- [2] Feinberg D, MRM, 2:555, 1985.
- [3] Galea D, Med Phys, 29:1719, 2002.
- [4] Carvalho J, MRM, 57:639, 2007.
- [5] DiCarlo J, MRM, 54:645, 2005.



**Figure 2.** Velocity spectra of pulsatile flow through a nozzle using 1 (a), 5 (b), 16 (c) and 30 (d) averages. Arrows indicate ghosting.



**Figure 3.** a) Velocity spectra using ungated FVE: CA – carotid artery, VA – vertebral artery, JV – jugular vein. b) Doppler ultrasound of CA.



**Figure 4.** a) Velocity spectra using ungated FVE: AA – ascending aorta, PA – pulmonary arch, SVC – superior vena cava. b) Doppler ultrasound of AA.