Variable Density Excitation Pulses in One-Shot Fourier Velocity Encoding for Valve Flow Imaging

D. Lee[1], J. C. DiCarlo[1], A. B. Kerr[1], J. M. Santos[1], J. M. Pauly[1]
[1]Electrical Engineering, Stanford University, Stanford, CA, United States

Introduction

Measurement of peak valve flow is important in diagnosing aortic and mitral stenosis. Since it doesn't suffer from partial volume effects, one-shot Fourier velocity encoding (FVE) has been shown to be an effective way of acquiring a velocity distribution in real-time [1,2]. By applying an oscillating readout gradient after the selected volume is restricted to a 2D cylinder, we can acquire a spatial-velocity distribution temporally resolved as in Figure 1. Reducing readout time by traversing k-space with variable sampling density improves temporal resolution, insensitivity to off-resonance and field inhomogeneity [3]. Similarly, we can achieve a shorter excitation pulse by adopting variable density in excitation k-space. This becomes most effective when a large excitation FOV with narrow beam width is desirable.

Theory

In designing a cylindrical excitation, there is a trade-off between sidelobe location and beam width for a given pulse duration. The former decides excitation field of view (FOV) and the latter is governed by the resolution (Δr). A k-space analysis of small-tip-angle excitation provides the PSF of the spiral excitation trajectory [4]. Since FOV and Δr are chosen to suppress unwanted signal which obscures the flow spectra, FOV is set large to avoid the signal from surrounding tissue and Δr is decided such that the beam width is not larger than the vessel but large enough to get strong signal from the blood. Thus, large FOV and small Δr is desired in this application and one way we can achieve this is by playing a long excitation pulse. But this is not desirable since it will increase profile sensitivity to off-resonance, field inhomogeneity, outflow effects and temporal resolution. To improve time efficiency, we adopted a variable density k-space approach so we could acquire an excitation profile with distributed and suppressed sidelobes with a shorter pulse duration. Due to the less coherent sidelobes and the fact that most of sidelobes reside in soft tissue, the contribution from sidelobes, which adds signal at zero velocity, is expected to be milder than that from the prominent sidelobes of the uniform k-space density approach. By suppressing this unwanted signal, we can effectively increase contrast in the velocity spectrum.

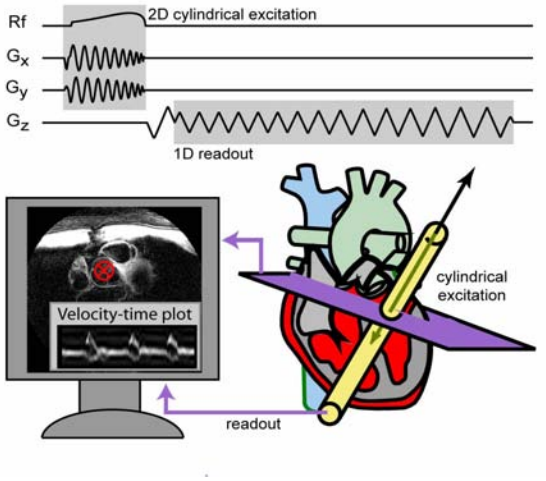

Figure 1. One-shot Fourier Velocity Encoding: A 2D RF pulse excites a cylinder passing perpendicularly through the mitral valve and an oscillating 1D readout gradient then resolves both the velocity spectrum and the position along the cylinder.

Methods

All the 2D selective excitation pulses were designed using a small-tip-angle approximation [4]. Density of the spiral k-space trajectory was chosen such that corresponding FOV linearly decreases in the radial direction. Designs were constrained by gradients of 40 mT/m maximum amplitude and 150 T/m/s maximum slew rate. RF weighting was applied to achieve a Gaussian-shaped circularly symmetric cylindrical excitation profile and the excitation k-space density was compensated by multiplying the differential annular area traversed by the spiral trajectory [5]. The width of a Gaussian-shaped cylindrical excitation is characterized by its full width at half-maximum (FWHM). Pulses were verified with both simulation and a slab phantom experiment in Figure 2-(a~d). In vivo measurement was done at the aortic valve using a real-time system for efficient prescription of the cylindrical excitation and monitoring of the velocity distribution [6]. A 5-inch surface coil was used and the velocity was measured with 400cm/s velocity FOV, 33.3cm/s velocity resolution, and 40ms temporal resolution.

Results and Discussion

With a real-time system being used for accurate excitation planning, we could successfully acquire the velocity spectra at the aortic valve in Figure 2-(e~h). First, we observed the benefit of using a narrower beam from Figure 2-(e,h). When we use a thicker excitation cylinder, we excite more soft tissue outside the vessel. From Figure 2-(e,f), we also found that variable density can be more efficient in suppressing zero-velocity coming from static tissue than uniform density when excitation time was set to be same. This is because variable density suffers less when the sidelobe is within the coil sensitivity region in the body. Finally, when we decreased the excitation time to 50% of the pulse time in (e,f), we still get a good spectrum as in Figure 2-(g).

In valve flow imaging, a variable density excitation improves the contrast of the velocity spectrum by achieving a narrow cylinder with suppressed and incoherent sidelobes in a shorter time.

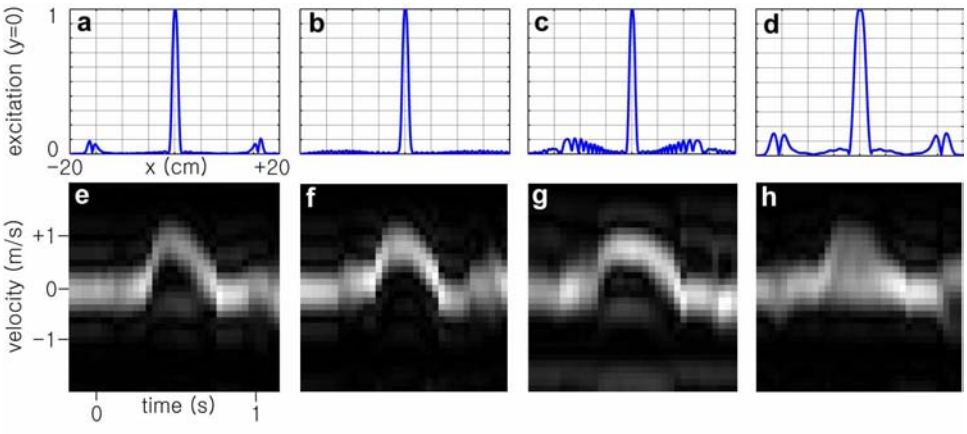

Figure 2. Excitation profiles acquired with slab phantom (a~d) and in vivo results measured at the aortic valve (e~f).
(a,e) Uniform density (N = 16)
: T_{exc} = 8.4ms, D = 1cm, FOV = 16cm
(b,f) Variable density (N = 19.2)
: T_{exc} = 8.4ms, D = 1cm, FOV = 35.2~3.2cm
(c,g) Variable density (N = 9.6)
: T_{exc} = 4.4ms, D = 1cm, FOV = 16~3.2cm
(d,h) Uniform density (N = 8)
: T_{exc} = 3.0ms, D = 2cm, FOV = 16cm
Note:
N: number of turns in spiral trajectory
T_{exc}: excitation pulse duration
D: diameter of cylincrical excitation (FWHM)
FOV: excitation field of view

References

[1] Hu BS et al., Magn. Reson. Med., 30:393-398 (1993)
[2] Luk Pat, GT et al., Magn. Reson. Med., 40:603-613 (1998)
[3] DiCarlo, JC et al., Magn. Reson. Med., 54:645-655 (2005)
[4] Pauly, JM et al., J. Magn. Reson., 81:43-56, (1989)
[5] Hardy, CJ et al., Magn. Reson. Med., 17:315-327 (1991)
[6] Santos, JM et al., IEEE EMBS 26th, 1048 (2004)