UNIVERSITY OF
SOUTHERN CALIFORNIA

Validation of the spiral Fourier velocity encoding method

Joao L. A. Carvalho, Jon F. Nielsen, Krishna S. Nayak

Department of Electrical Engineering, University of Southern California, Los Angeles, CA, United States

USC Viterbi
School of Engineering

MREL - USC

Introduction:

Phase-contrast (PC) is the current “gold standard” for MR flow quantitation, despite suffering from partial volume effects [1]. Fourier velocity encoding (FVE) resolves the distribution of velocities within each voxel, allowing larger voxels to be used [2]. Although the scan-time of 2DFT FVE is prohibitively long, the recently introduced spiral FVE method [3] shows promise as it is 10 to 40 times faster. In this work, we provide an initial validation of spiral FVE in a carotid artery flow phantom, using ultra-high-resolution PC as the gold standard.

Our motivation to apply spiral FVE to the carotid arteries stems from 1995 work of Frayne and Rutt [4], who proposed 2DFT FVE as a method for non-invasively measuring fluid shear rate and hence vascular wall shear stress, an important factor implicated in atherogenesis. We are interested in revisiting this approach using ultra-fast FVE methods.

Theory:

The spiral FVE method (Figure 1) acquires a stack-of-spirals in k_x,k_y,k_v space (Figure 2), where k_v is the Fourier variable associated with the velocity distribution. Truncation in k-space follows a cylindrical shape, i.e. circular along k_x,k_y, and rectangular along k_v. The associated object domain blurring can be modeled as convolution of $m(x,y,v)$ with jinc(r) and sinc(v).

Methods:

Experiments were performed on a GE Signa Excite HD 3T scanner with a pulsatile carotid flow phantom (Phantoms by Design, Inc., Bothell, WA), shown on Figure 3. A slice perpendicular to the carotid bifurcation was prescribed, and through-plane velocities were measured. A gradient-echo 2DFT phase-contrast sequence (0.33 mm resolution, 10 NEX) was used as a gold standard reference. Spiral FVE data with 3 mm resolution was obtained from the same scan plane. Acquisitions were prospectively gated, and we used the same TR, flip angle, slice profile and pre-scan settings for both acquisitions. **The total scan time was 40 minutes for PC, and 12 seconds for FVE.**

A simulated FVE dataset $s(x,y,v)$ was derived from the PC data using the following model:

$$s(x,y,v)=\left(m(x,y)\cdot \mathrm{sinc}\frac{v-v_{PC}(x,y)}{v_{res}}\right)*\mathrm{jinc}\frac{\sqrt{x^2+y^2}}{xy_{res}},$$

where $m(x,y)$ and $v_{PC}(x,y)$ are the magnitude and velocity images, v_{res} is the FVE velocity resolution, and xy_{res} is the FVE spatial resolution.

Registration between PC-derived and measured FVE data was performed by using the k-space phase difference (between PC-derived and FVE) to estimate the spatial shift between the two datasets. Amplitude scaling was performed by normalizing the total energy in each of the two datasets to a common value.

Results:

For reference, magnitude and phase-difference images obtained from the first temporal phase of the phase-contrast data are shown in Figure 4.

The results for two representative pixels are shown in Figure 5. PC-derived (left) and measured (center-left) FVE histograms are in good agreement. The difference between histograms has 10dB less energy than the reference histogram (center-right).

These results suggest that spiral FVE provides velocity histograms in agreement with those obtained using ultra-high-resolution 2DFT phase-contrast, in considerably shorter scan time.

Discussion and Conclusion:

Spiral FVE is a time-efficient flow measurement method that provides spatially and temporally resolved velocity distributions in short acquisitions. It has been shown to work well in vivo for the evaluation of carotid and cardiac flow [3], and has great potential for acceleration [5].

Velocity histograms obtained with spiral FVE showed good visual agreement with those obtained using high-resolution PC, As future work, we will explore the use of spiral FVE for non-invasive measurement of wall shear rate.

References:

[1] Tang C, et al. JMRI 3:377, 1993.
[2] Moran PR. MRI 1:197, 1982.
[3] Carvalho JLA, et al. MRM 57:639, 2007.
[4] Frayne R, et al.MRM 34:378, 1995.
[5] Carvalho JLA, et al. Proc ISMRM 15:588, 2007.

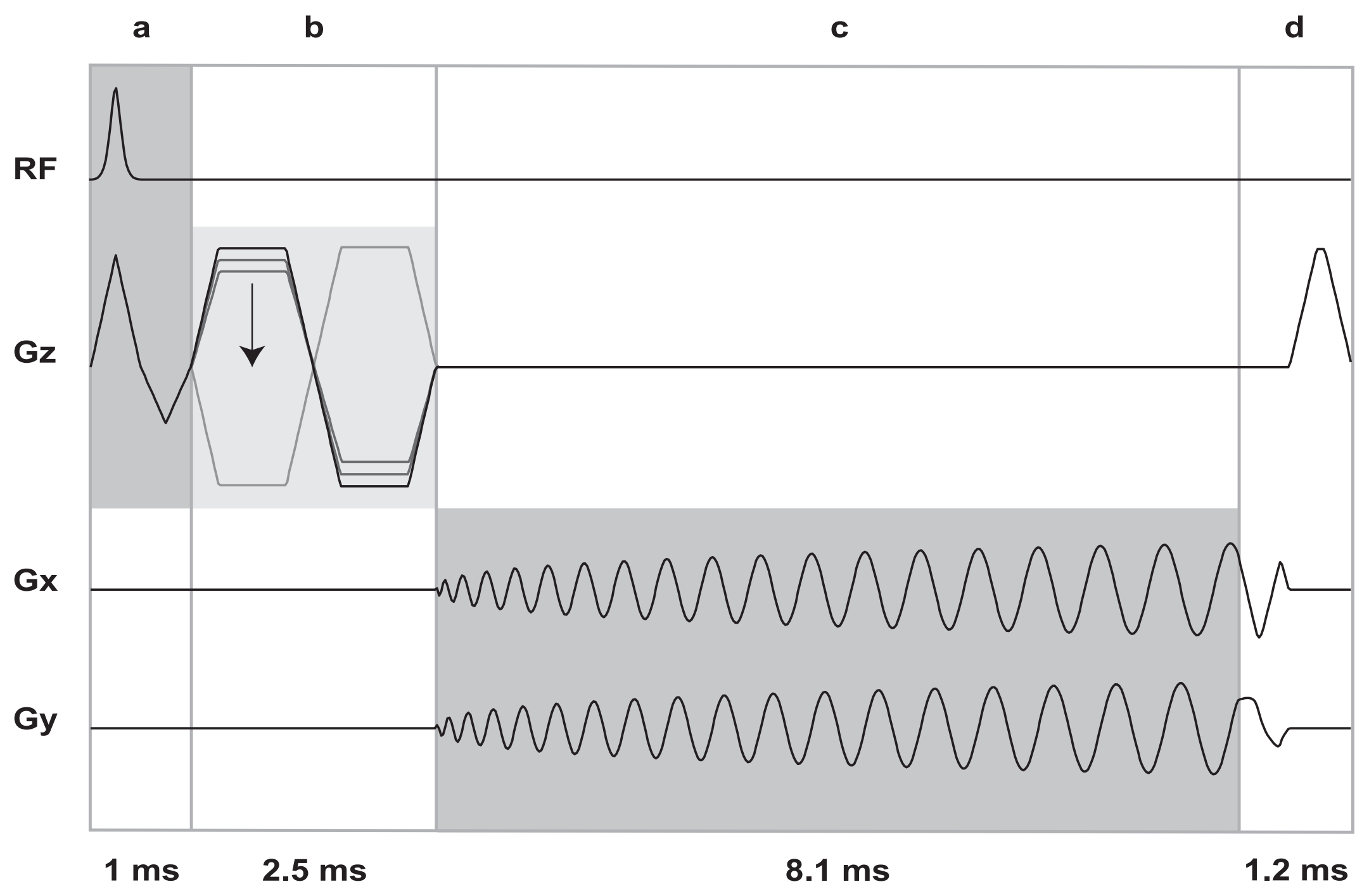

Figure 1: Spiral FVE pulse sequence: (a) slice selective excitation, (b) velocity encoding bipolar gradient, (c) spiral readout, and (d) refocusing and spoiler gradients.

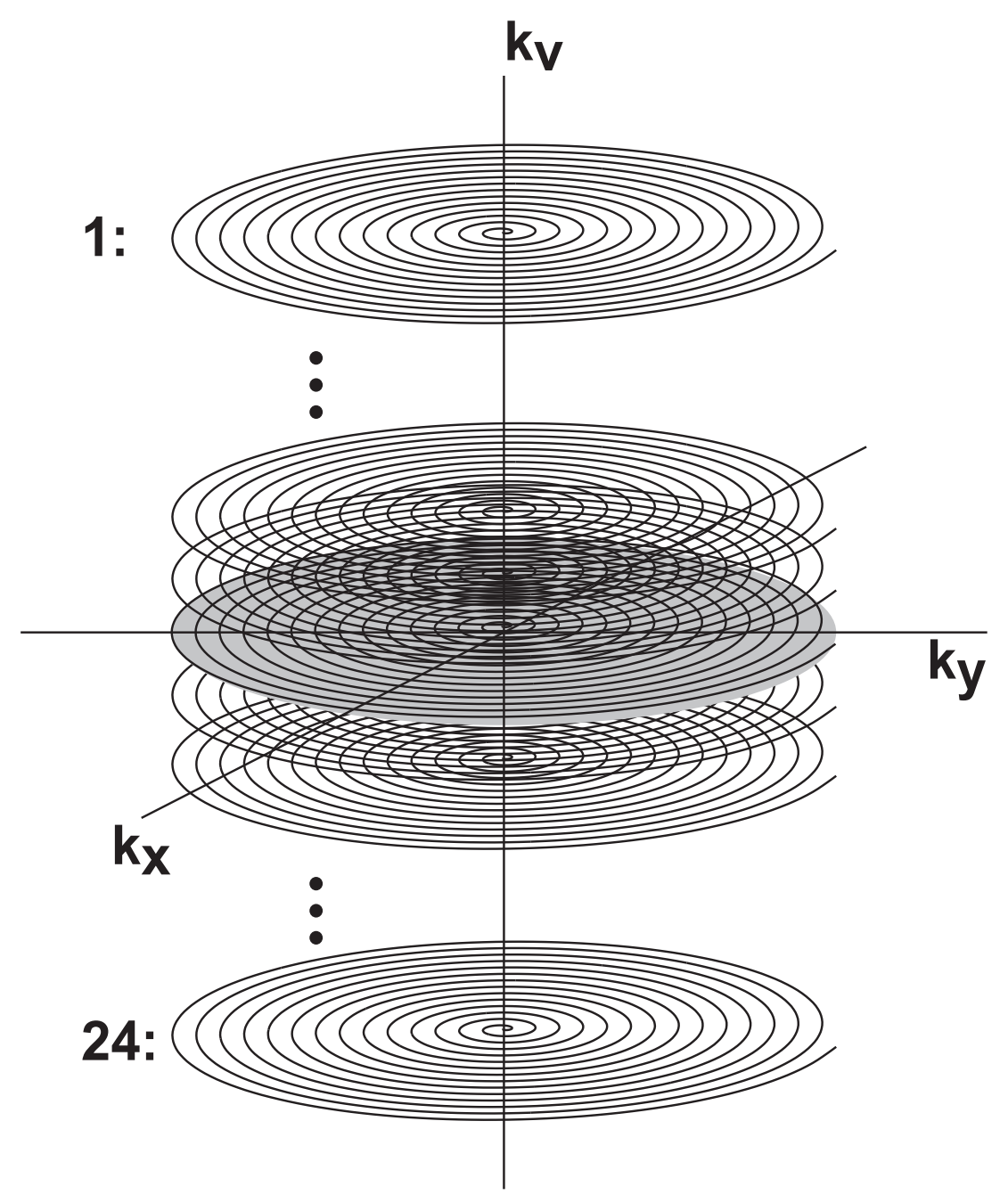

Figure 2: Fourier domain k-space sampling scheme. The dataset corresponding to each temporal frame is a stack-of-spirals in k_x,k_y,k_v space. The bipolar gradient phase-encodes in k_v, while each spiral readout acquires one “platter” in k_x,k_y. The 3D inverse Fourier transform of this data represents the signal distribution in x,y,v.

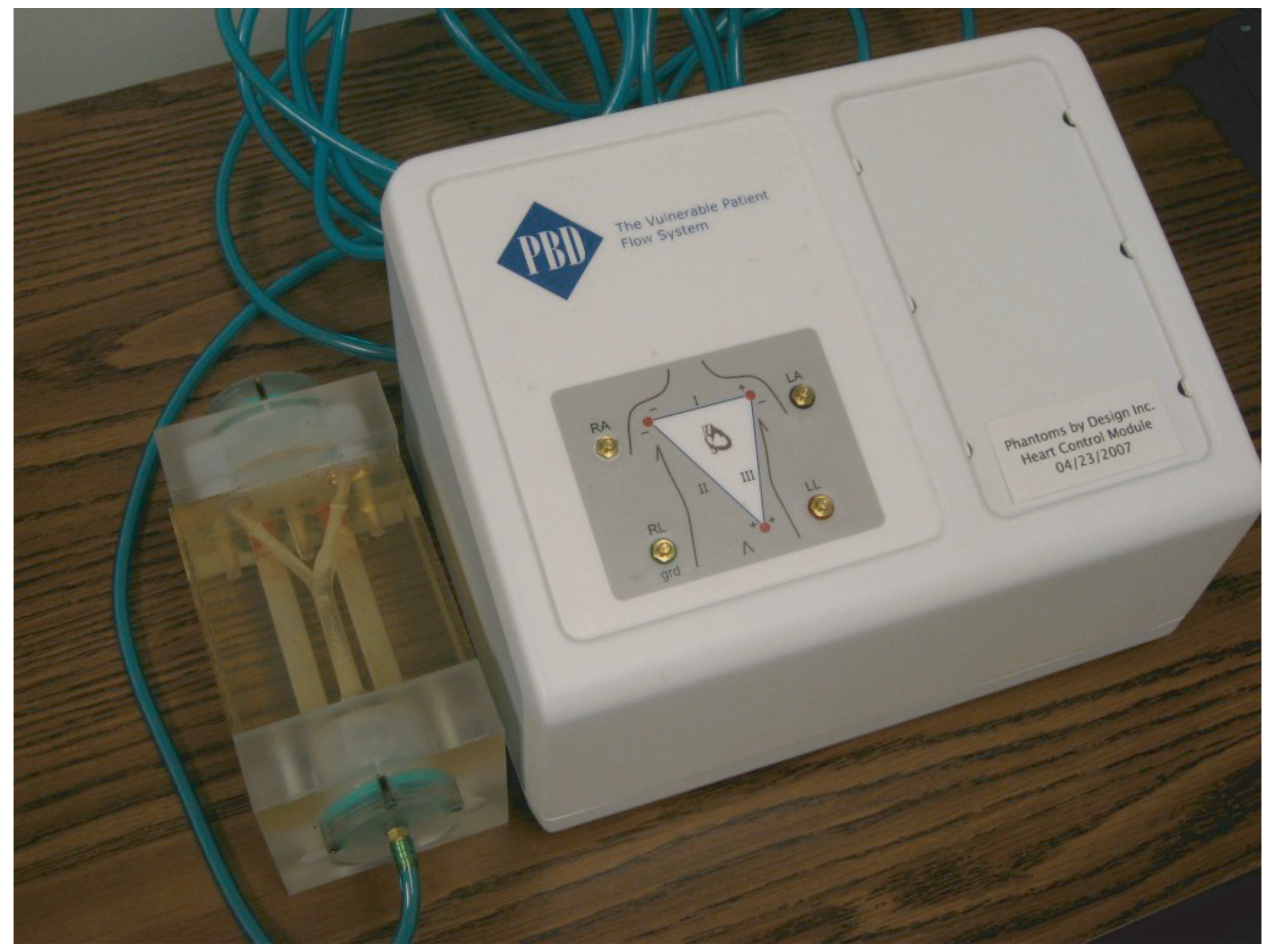

Figure 3: Pulsatile carotid flow phantom (Phantoms by Design, Inc., Bothell, WA).

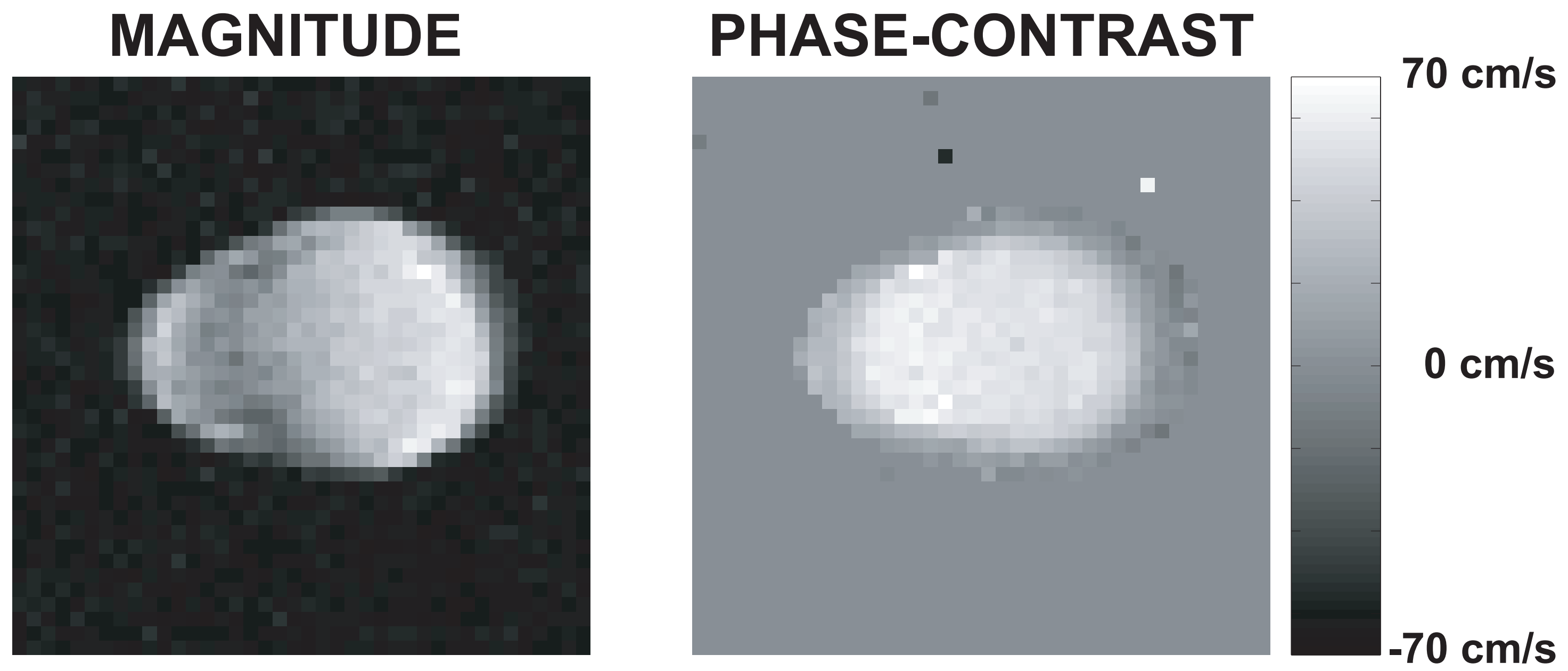

Figure 4: Magnitude and phase-difference images obtained from the first temporal phase of the PC data.

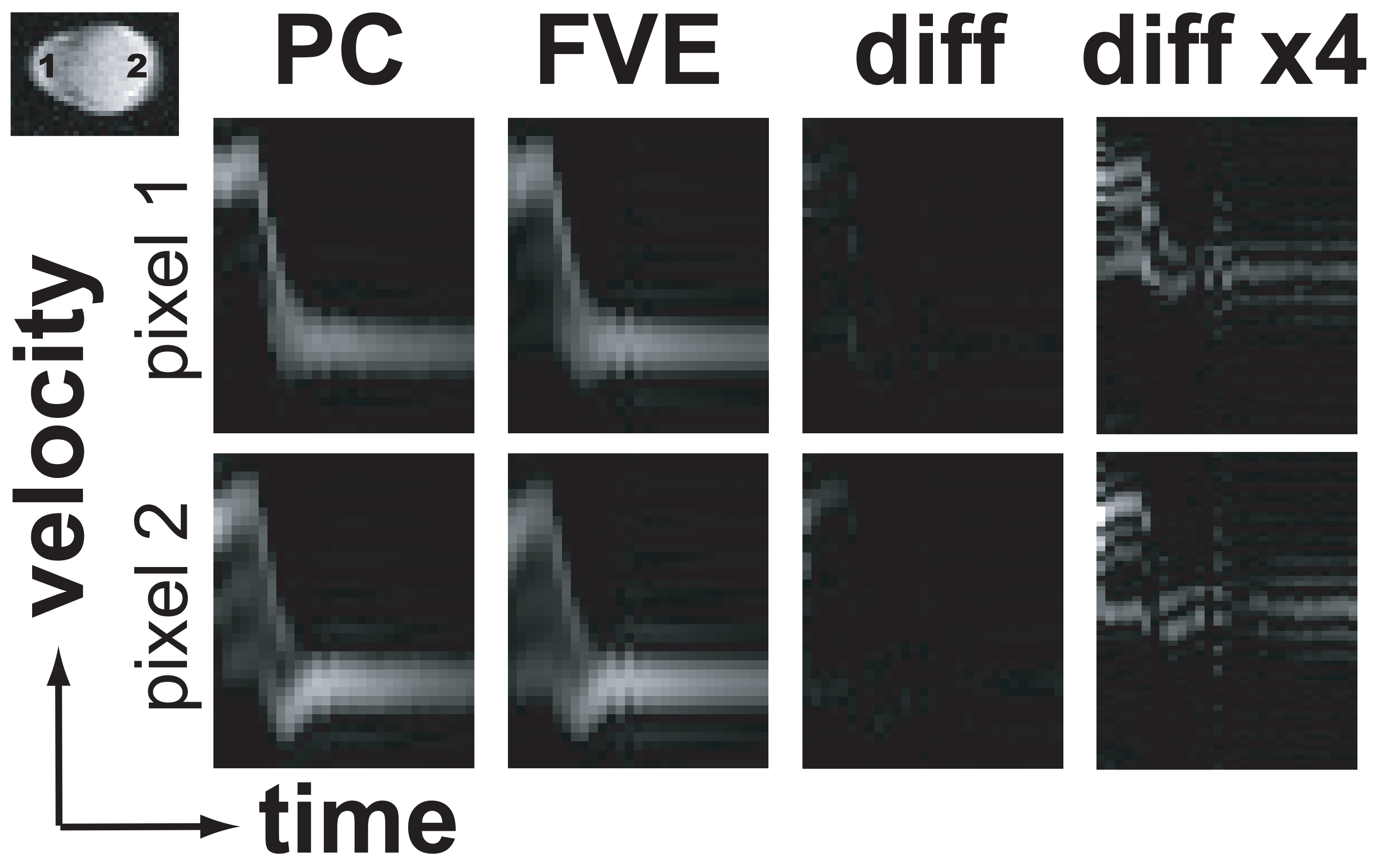

Figure 5: Spiral FVE validation against high-resolution 2DFT phase-contrast, using a pulsatile carotid flow phantom. The PC-derived FVE histogram (left) agrees very well with the measured spiral FVE data (center-left). The difference between histograms (center-right) has 10dB less energy than the reference histogram. Pixels 1 and 2 were selected near opposite vessel walls (upper-left corner).