

Universidade de Brasília

PGEA
PÓS-GRADUAÇÃO EM ENGENHARIA DE SISTEMAS ELETRÔNICOS E DE AUTOMAÇÃO

High-resolution, high-SNR velocity maps reconstructed from low-resolution Fourier velocity encoded MRI data

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ISMRM 2013, 21st Annual Meeting Salt Lake City April 22, 2013

Declaration of Relevant Financial Interests or Relationships

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I have no relevant financial interest or relationship to disclose with regard to the subject matter of this presentation.



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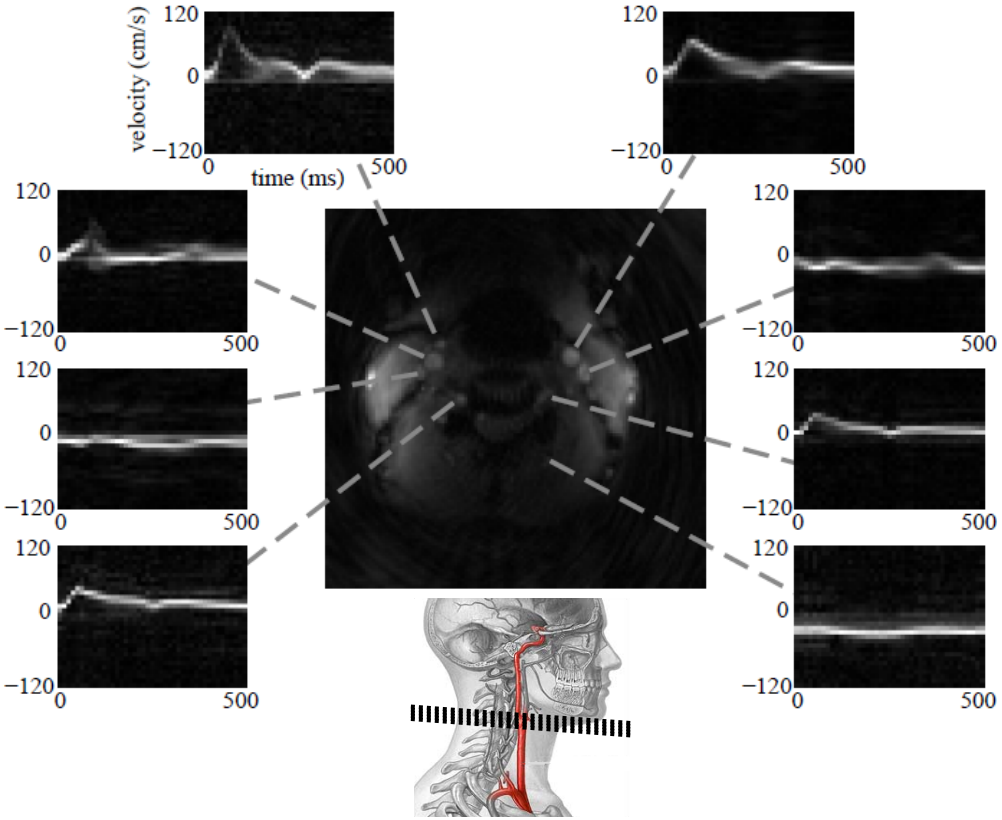
Phase contrast (PC)

- Current gold standard for MRI flow quantitation
- Affected by partial-volume effects [1]
  - Complex/turbulent flow
  - Lumen/vessel wall interface
- Solution: increase spatial resolution
  - Lower SNR
  - Longer scan time

[1] Tang C. et al. JMRI 3:377, 1993.

Fourier Velocity Encoding (FVE)

- Resolves the distribution of velocities $s(v)$ within each voxel [2]
- Robust to partial-volume effects
- Usually acquired with low spatial resolution
- Multidimensional: x,y,v,t
  - Considerably higher SNR
  - Longer scan time



[2] Moran PR. MRI 1:197, 1982.

FVE Signal Model

- PC provides two spatial maps: $m(x,y)$ and $v_0(x,y)$
- FVE provides the spatial-velocity distribution: $s(x,y,v)$
- If spatial resolution is sufficiently high:

$$s(x,y,v) = \left[m(x,y) \times \delta\left(v - v_0(x,y)\right) \right] * \mathrm{sinc}\left(\frac{v}{\Delta v}\right)$$

magnitude map

velocity map

k_v truncation effect

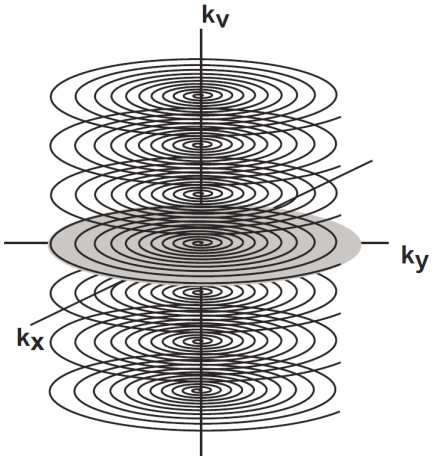
Δv: FVE velocity resolution

δ: Dirac's delta function

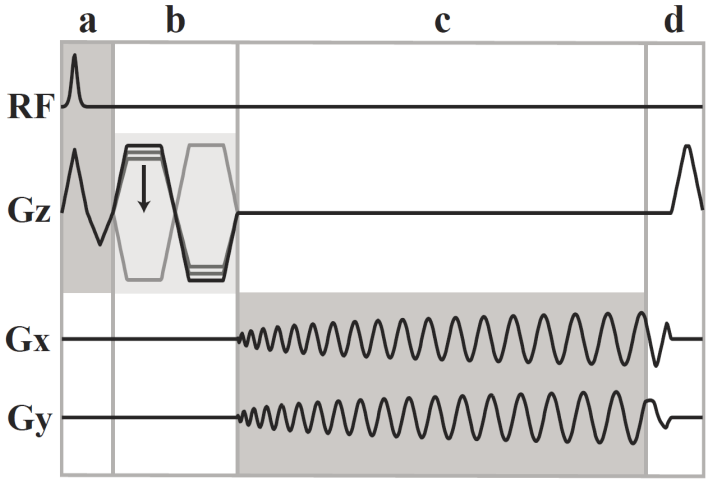
Spiral FVE (sFVE)

- Rapid method for FVE-based velocity-distribution measurement [3,4]
- Fully localized, time-resolved velocity distributions in a short breath-hold [3]
- Accurately captures peak velocities in jets [5]
- Useful in estimating wall shear rate [6]

k-space



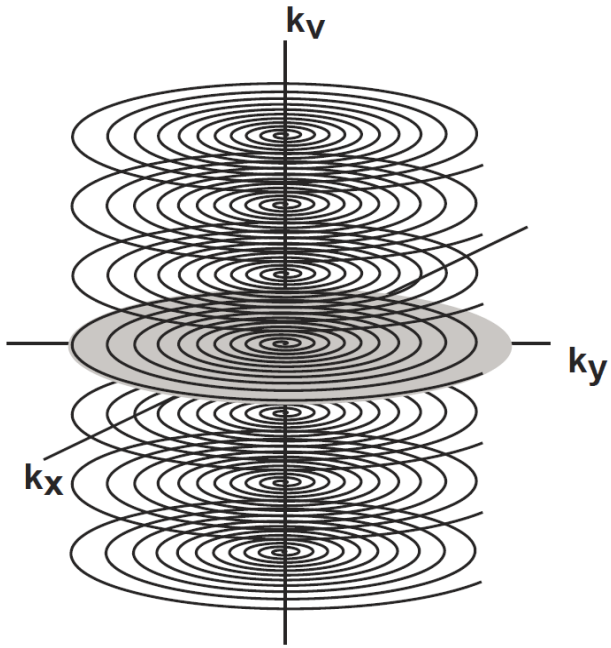
pulse sequence



[3] Carvalho JLA and Nayak KS. MRM 57:639, 2007.
[4] Lyra-Leite et al. ISMRM 21:1352, 2013.
[5] Steeden JA et al. MRM 67:1538, 2012.
[6] Carvalho JLA et al. MRM 63:1537, 2010.

Spiral FVE Signal Model

- k-space truncation:
  - circular along k_x-k_y: $\mathrm{jinc}(r/\Delta r)$
  - rectangular along k_v: $\mathrm{sinc}(v/\Delta v)$



Δv: FVE velocity resolution

Δr: FVE spatial resolution

Spiral FVE Signal Model

- k-space truncation:
  - circular along k_x-k_y: $\mathrm{jinc}(r/\Delta r)$
  - rectangular along k_v: $\mathrm{sinc}(v/\Delta v)$
- $s(x,y,v)$, may be modeled from $v_0(x,y)$ as [6]:

$$s(x,y,v) = \left[m(x,y) \times \mathrm{sinc}\left(\frac{v - v_0(x,y)}{\Delta v} \right) \right] * \mathrm{jinc}\left(\frac{\sqrt{x^2 + y^2}}{\Delta r} \right)$$

k_v truncation effect

k_x-k_y truncation effect

Δv: FVE velocity resolution
Δr: FVE spatial resolution

[6] Carvalho JLA, et al. MRM 63:1537, 2010.

Estimating $v(x,y)$ from $s(x,y,v)$

- Spatial blurring effects are reduced using the deconvolution algorithm proposed in ref. [7], and we obtain:

$$\tilde{s}(x,y,v) \approx \left[m(x,y) \times \operatorname{sinc}\left(\frac{v - v_0(x,y)}{\Delta v} \right) \right]$$

- If a high-resolution spin-density map, $\tilde{m}(x,y)$, is available, the velocity $\tilde{v}$ at position (x_0,y_0) may be estimated from $\tilde{s}(x,y,v)$ as:

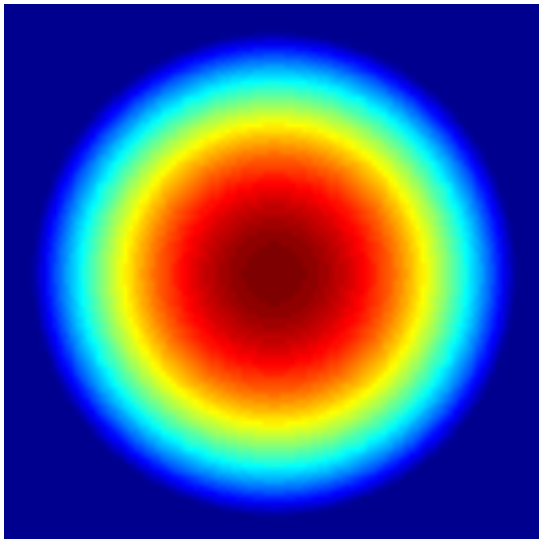
$$\tilde{v}(x_0,y_0) = \underset{\mu}{\operatorname{argmin}} \left\| \frac{\tilde{s}(x_0,y_0,v)}{\tilde{m}(x_0,y_0)} - \operatorname{sinc}\left(\frac{v-\mu}{\Delta v} \right) \right\|_2$$

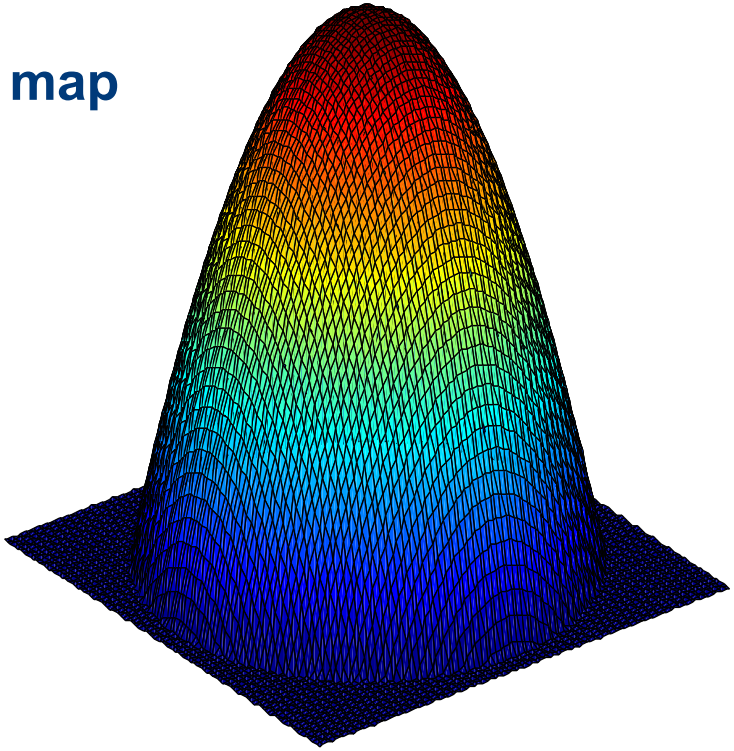
[7] Krishnan D and Fergus R. Proc 24th NIPS, 2009.

Experiment 1: Proof of Concept

- Simulated sFVE data (1 mm spatial resolution) was derived from a parabolic-flow numerical phantom (0.33 mm spatial resolution)

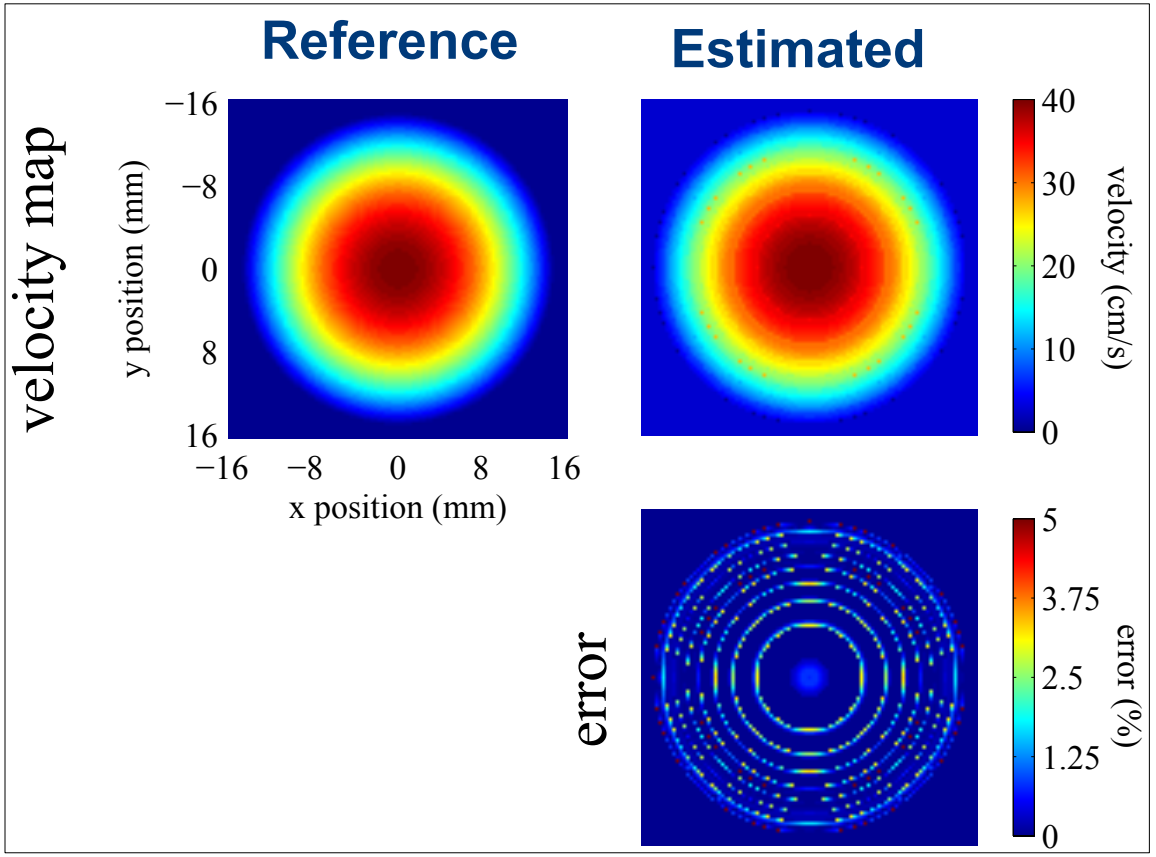
reference map





Proof of Concept: Results

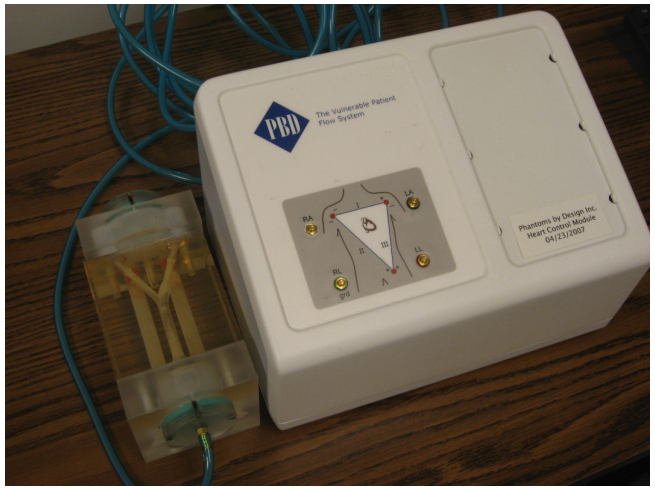
- Estimated velocity map was accurate within 3% for the vast majority of the pixels
- Important result! (carotid flow distant to bifurcation is approximately parabolic)



Experiment 2: Phantom Demonstration

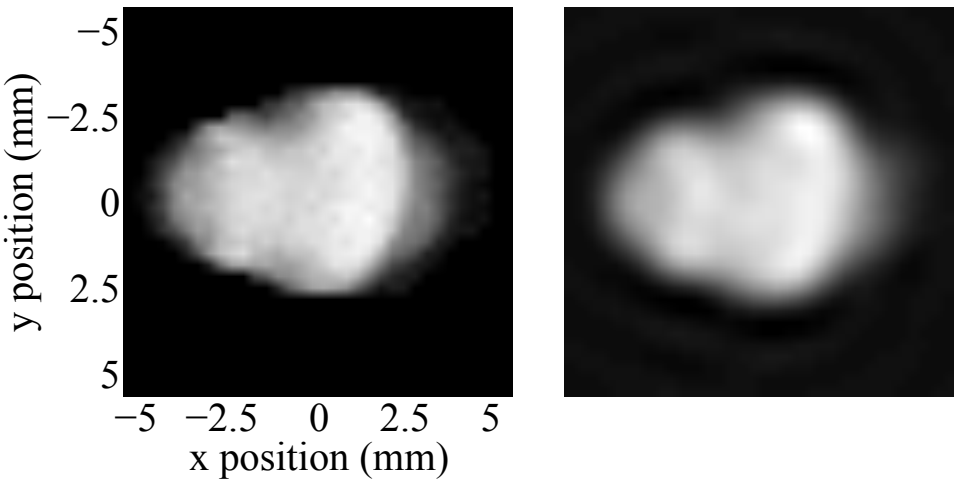
- Simulated sFVE data
  - 1 mm spatial resolution
  - Derived from PC data (0.33 mm spatial resolution)
  - Measured at the bifurcation of a carotid flow phantom
- Pulse sequence: cine gradient-echo 2DFT PC sequence
  - 10 NEX; 80 cm/s Venc

carotid flow phantom



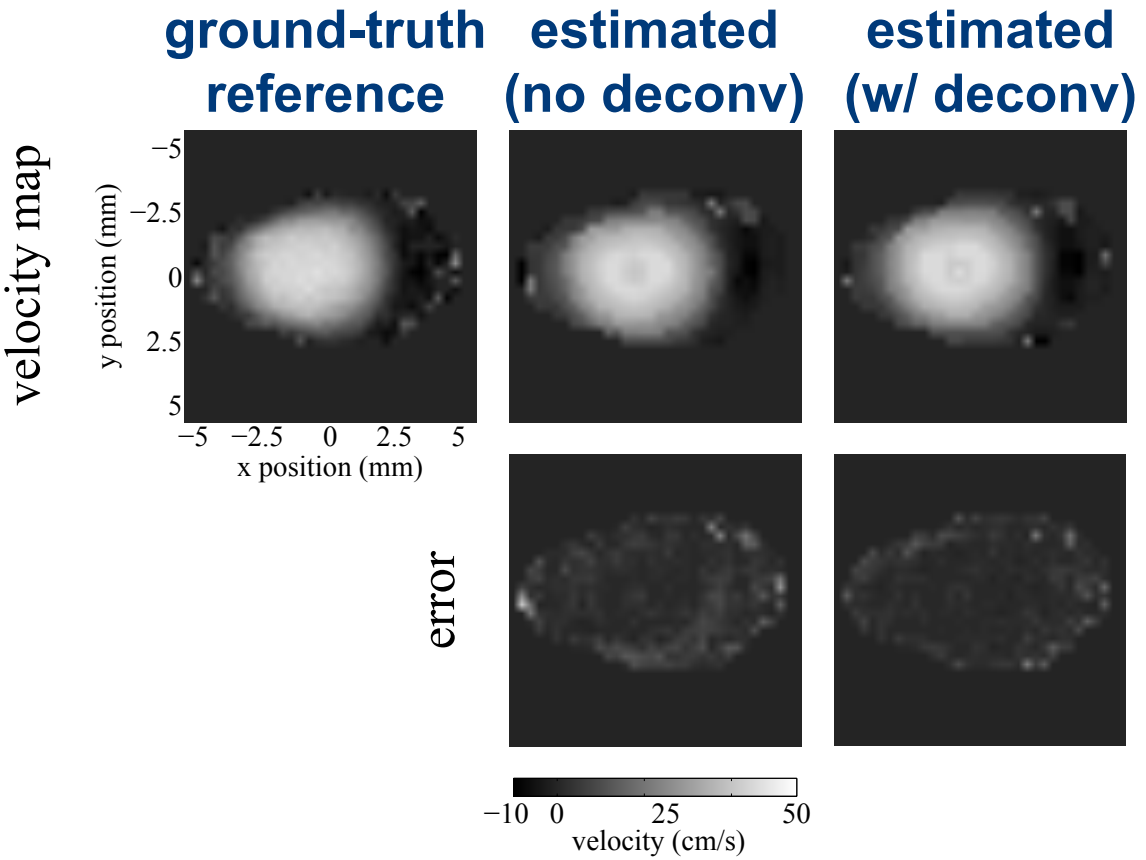
spin-density map

PC (0.33 mm) **sFVE (1 mm)**



Phantom Demonstration: Results

- Hi-res velocity maps estimated from low-res sFVE are qualitatively similar
- Spatial deconvolution (FVE-domain deblurring) improved accuracy



Conclusions

- Possible to obtain reasonably accurate hi-res velocity maps from low-res FVE distributions
- **Future work:**
  - Verify:
    - Higher SNR than PC?
    - Robust to partial voluming?
  - Use FVE for driving CFD of carotid flow [8]

[8] Nielsen J-F and Nayak KS. Proc ISMRM 17: 3858, 2009.



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GPSIM
Grupo de Processamento de Sinais e Imagens Médicas

Thank you!

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Financial Support: - DPP/UnB
- ISMRM