Clinical applications for spiral flow imaging – Part II

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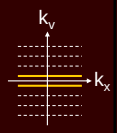
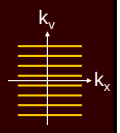
MR flow quantitation

- Phase contrast [O'Donnell, 1985]
  - Fast
  - One velocity estimate for each voxel



- Fourier velocity encoding (FVE) [Moran, 1982]
  - Slow
  - Velocity distribution in each voxel



Techniques and applications

1. Spiral FVE
   - Carotid wall-shear stress
2. Spiral phase-contrast
   - Stroke volume variability

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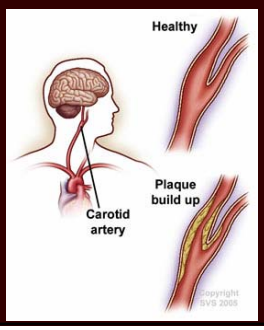
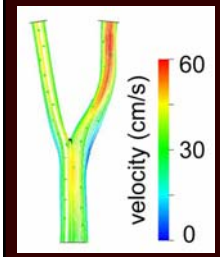
1. ***Spiral FVE***
   - ***Carotid wall-shear stress***
2. Spiral phase-contrast
   - Stroke volume variability

Motivation

Carotid Atherosclerosis



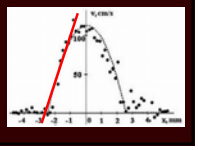
Wall-shear stress



WSS = μ dv/dr

blood viscosity

spatial variation of blood velocity



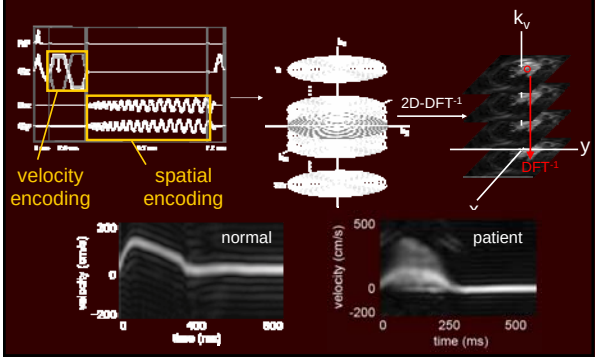
Plaque ↔ high WSS [Thubrikar, 1995]

No non-invasive gold standard

Measuring dv and dr

- "dv" is measured with flow encoding
- Problem: "dr" is sub-millimeter
- Phase contrast
  - partial volume
- FVE
  - Needs 2D spatial localization
  - Prohibitively slow
- We propose using Spiral FVE

Spiral FVE

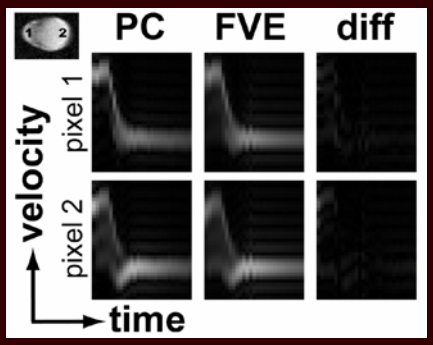


Spiral FVE - Validation

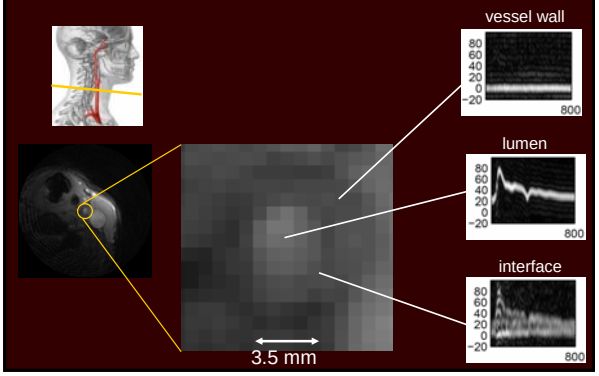
- Validation against hi-res phase contrast
- Pusatile flow phantom
- PC-derived FVE
  - Sinc blurring along v
  - Jinc blurring along x,y

PC m(x,y) v(x,y) —sinc(v), jinc(x,y)→ **FVE** s(x,y,v)

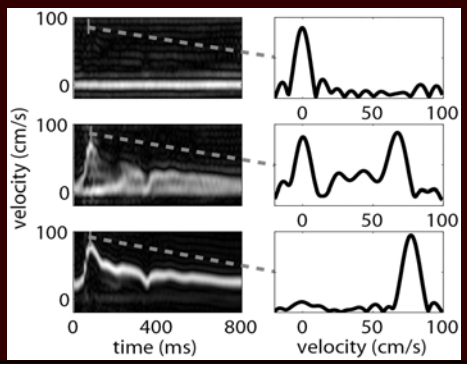
Spiral FVE - Validation



Carotid flow waveforms

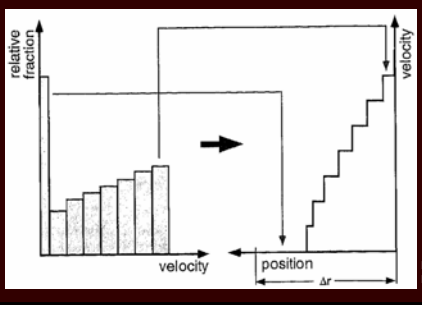


Flow distributions



Frayne method

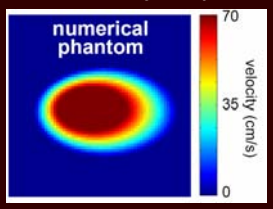
- Models v(r) from s(v)



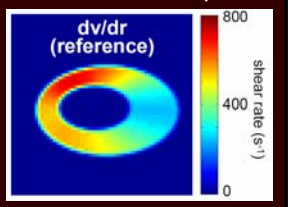
Frayne 1995
MRM 34:376

Shear rate numerical phantom

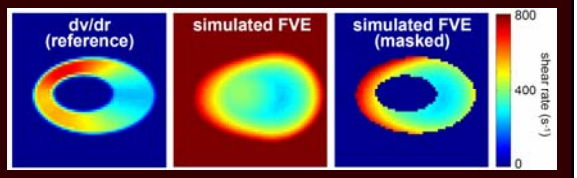
velocity map

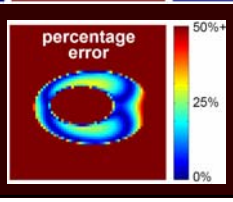


shear rate map



Simulation results



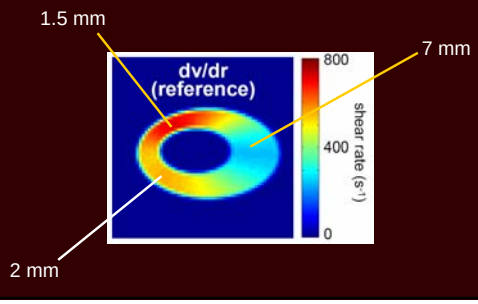


Resolution requirements

Velocity res. (cm/s)	Spatial resolution (mm) 7	5	4	3	2	1.5	1
60	53±15	37±19	30±14	27±19	53±45	99±61	191±91
30	58±14	45±18	35±17	26±12	25±23	47±38	105±56
20	52±19	40±15	33±13	24±10	16±14	26±20	62±37
15	38±16	32±18	25±16	17±11	18±12	20±24	47±39
10	34±16	28±13	22±12	15±10	22±22	17±18	41±41
7.5	33±16	28±13	22±12	16±10	22±23	17±18	40±45
5	34±16	28±13	22±12	16±10	23±25	17±18	42±49
3.8	34±16	28±13	22±12	15±10	24±28	17±18	44±51

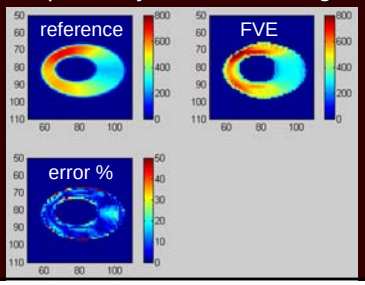
Optimal spatial resolution

- Depends on width of viscous sublayer (dr)

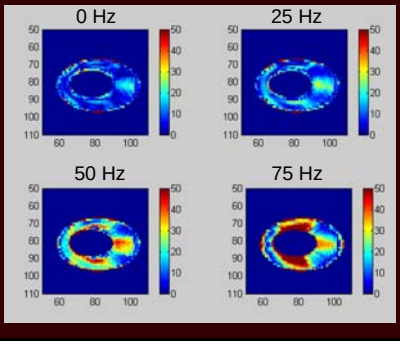


Spatially varying resolution

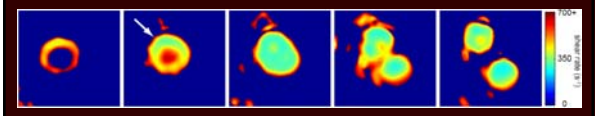
- Use high resolution
- Retrospectively blur certain regions



Off-resonance simulation



In vivo demonstration



Techniques and applications

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   - ***Stroke volume variability***

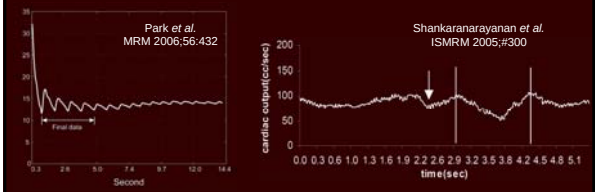
Stroke volume

- Volume ejected by LV per heartbeat
- Applications: ischemia, valve disease, hypertension, lung disease
- Stroke Volume Variability (SVV):
  - indicator of sympathetic response
  - connects heart rate variability (HRV) to blood pressure and venous return variabilities

No non-invasive gold standard!

Recent methods in MRI

- Averaged through several heartbeats
- Can measure cardiac output only

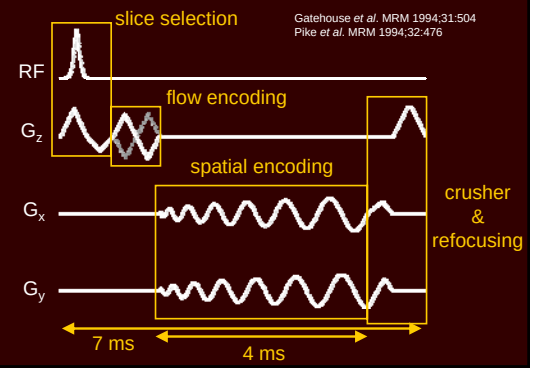


- We propose measuring beat-to-beat SV

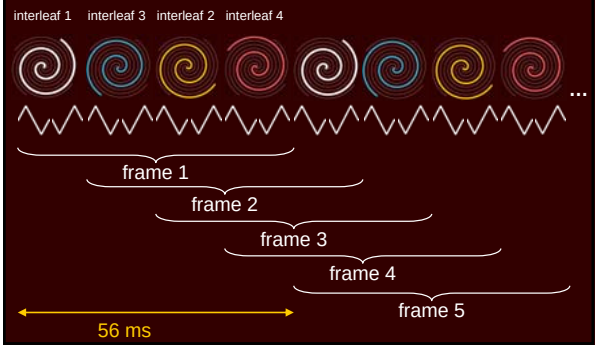
Scan parameters

- Variable-density spiral phase contrast
  - Interleaves: 4
  - Resolution: 3 mm
  - FOV: 25~6 cm
  - Venc: 200 cm/s
  - Temporal resolution: 56 ms

Pulse sequence



View ordering

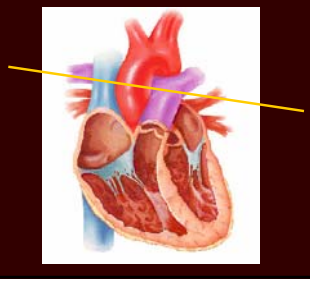


Assumptions

- Partial volume:
  - PC velocity = average velocity within the voxel
  - Flow in voxel = voxel size x PC velocity
- Variable density spiral: aliasing artifacts are insignificant within the ROI

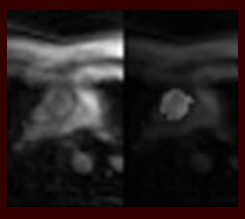
Slice prescription

- Perpendicular to aorta
- Before main bifurcations

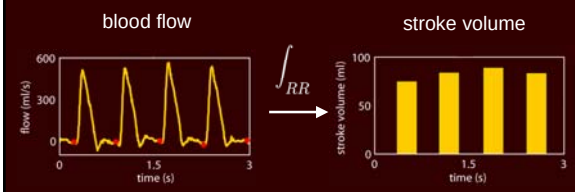


ROI following

- Velocity and magnitude thresholds
- Recalculated every heartbeat



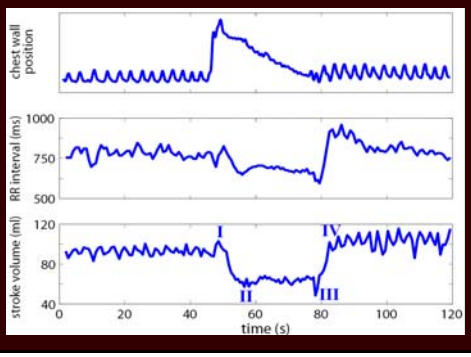
Stroke volume calculation



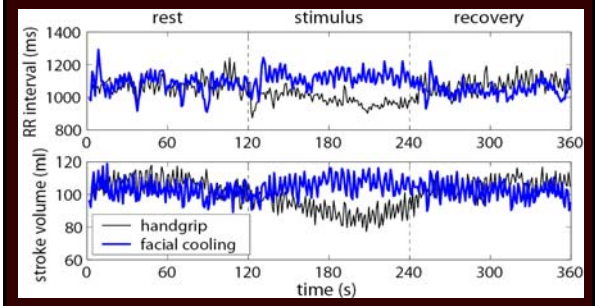
Stimuli

- Valsalva maneuver
- Handgrip
- Facial cooling
- Mental stress
- Cold pressor

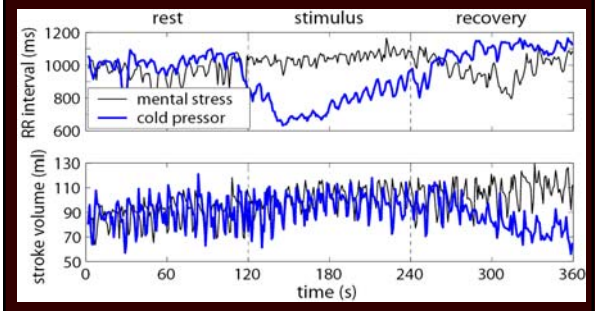
Results – Valsalva maneuver



Handgrip & facial cooling



Mental stress & cold pressor



Conclusion

- We can't validate the technique non-invasively
- The results are in agreement with our expectations based on our current understanding of the physiology

The End

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