Clinical applications for spiral flow imaging

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Previous talks

- Non-Cartesian reconstruction (2005)
- Spiral FVE (Spring 2006)
  - Aortic flow
  - Carotid flow
- Accelerated spiral FVE (Fall 2006)

2007?

Clinical applications

- Coronary flow
- Wall-shear stress in carotids
- Cardiac output

Clinical applications

- ***Coronary flow***
- Wall-shear stress in carotids
- Cardiac output

Coronary flow: Motivation

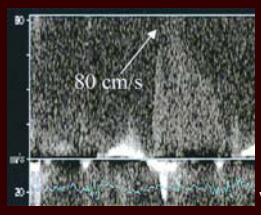
- Coronary stenosis is most common form of heart disease
- Kills 500k/year in U.S .

UMaine 2005

Miller 2004

Coronary flow: Motivation

- Flow quantitation → pressure drop
- Gold standard: intracoronary Doppler
  - invasive



Voci 2001

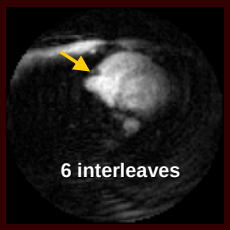
Coronary Flow in MRI

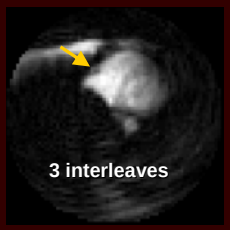
- Vessel is small
- Phase contrast
  - Partial volume
- FVE
  - Must be fast
  - Needs good spatial localization

Spiral FVE!!!

Coronary spiral FVE

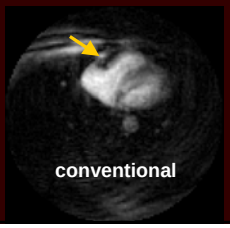
- Variable-density spirals
  - 3 interleaves is enough? (3.6 x 3.6 mm)

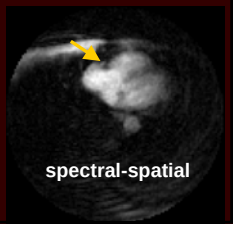




Fat supression

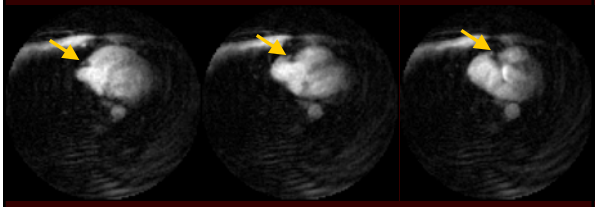
- Coronary is surrounded by FAT
  - Spectral-spatial pulse
  - Longer TR (13 ms)
  - Lower temporal resolution





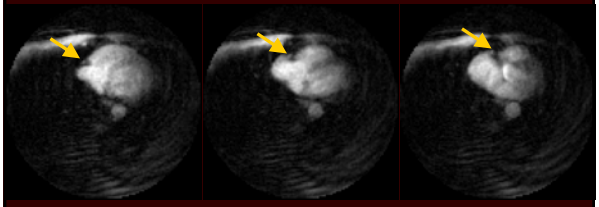
Region of Interest

- Vessel moves in plane



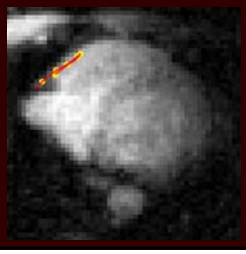
ROI following

- Operator clicks on coronary in a few cardiac phases



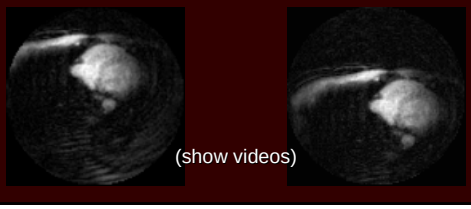
ROI following

- Operator clicks on coronary in a few cardiac phases
- Interpolate movement for other phases



In reconstruction

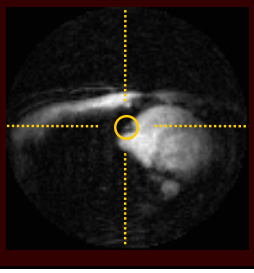
- In each cardiac phase, the FOV is re-centered
- Coronary artery always at center
- Heart and chest move, coronary doesn't



(show videos)

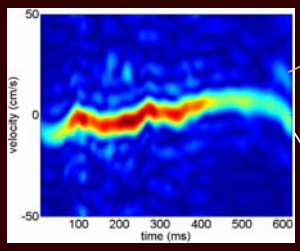
ROI prescription

- ROI prescribed as before:
  - draw small circle at center of FOV



Result (?)

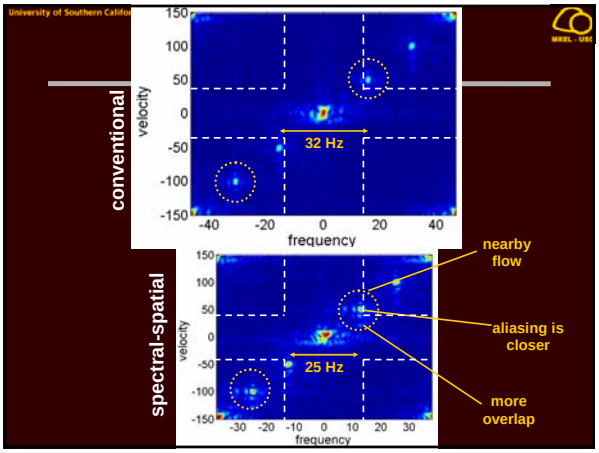
- Not sure if this is really coronary flow…



- What does coronary flow look like in normals?

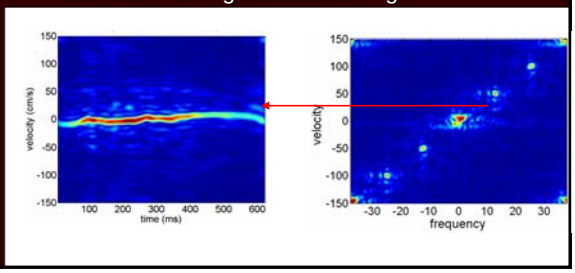
Temporal acceleration

- Longer TR → Lower temporal bandwidth
- Lots of pulsating neighbors
- More overlap in *v-f*
  - more aliasing!
- Needs to be reconsidered



Ghosting artifacts

- Aliasing that is not properly filtered becomes ghosting artifact
- Too much filtering causes blurring



Coronary flow: Future work

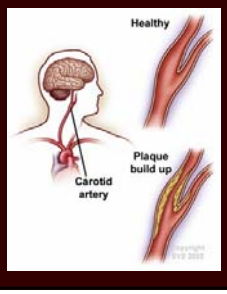
- Get actual coronary flow ☺
- Figure out the appropriate temporal acceleration scheme

Clinical applications

☑ Coronary flow
- ***Wall-shear stress in carotids***
- Cardiac output

Carotid Atherosclerosis

- Carotid arteries become blocked with plaque

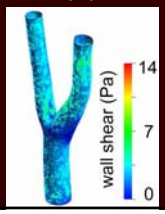


Related risks

- May show no symptoms
- Plaque fragments
- Particles circulate through blood
- Blood flow to brain becomes blocked
- Stroke!
- Prevention is important!

Wall-shear stress: Motivation

- "WSS is the frictional force that blood flow exerts at surface of the vessel wall"
- Plaque grows in regions of low WSS
- Tracking WSS may prevent plaque

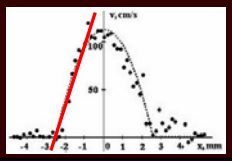


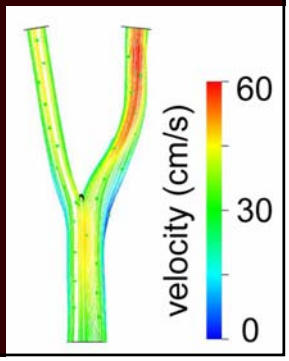
Measuring WSS

- WSS = μ dv/dr

blood viscosity

spatial variation of blood velocity





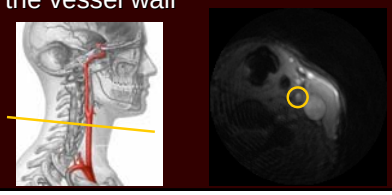
Measuring dv and dr

- "dv" is measured with flow encoding
- Problem: "dr" is sub-millimeter
- Phase contrast
  - partial volume
- FVE
  - Must be fast
  - Needs 2D spatial localization

Spiral FVE!!!

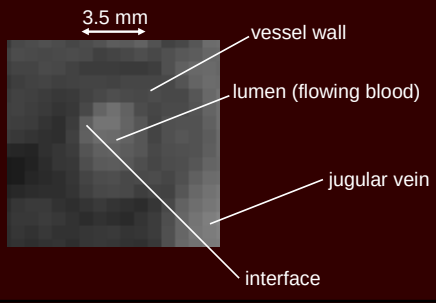
Measuring WSS with spiral FVE

- Prescribe slice perpendicular to carotid
- Acquire velocity-encoded data with high spatial resolution
- Draw a small region of interest around the vessel wall

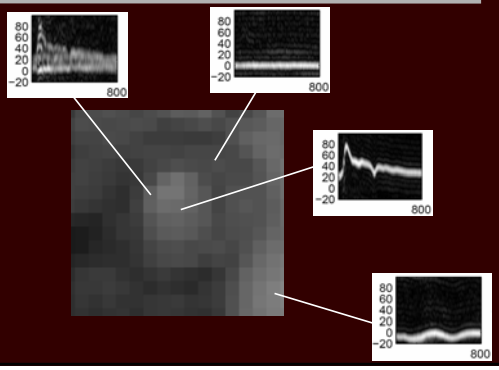


Measuring WSS with spiral FVE

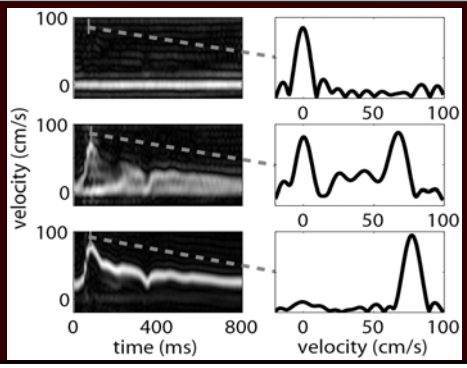
- Common carotid in cross-section



Flow waveforms

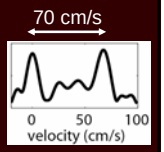


Flow distributions



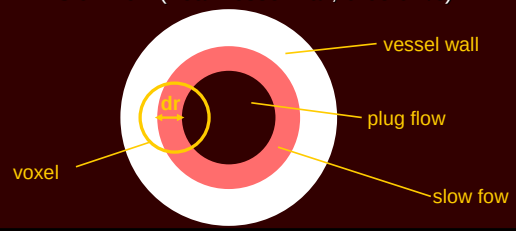
Estimating WSS from distributions

- Data we have
  - Velocity distribution for a voxel at wall-lumen interface
  - Voxel size
- Information we want:
  - "dv"
  - "dr"
- We know "dv"
- How to estimate "dr"?



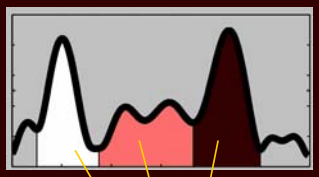
Estimating “dr”

- The voxel is partially occupied by:
  - Static material (vessel wall, 0 cm/s)
  - Plug flow (lumen, 65-80 cm/s)
  - Slow flow (near vessel wall, 0-65 cm/s)



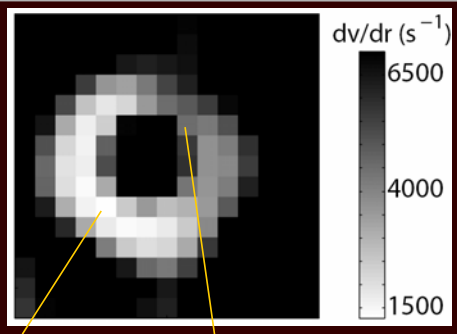
Estimating “dr”

- Find the areas (%) in flow distribution



- From the % areas, use geometry to find “dr”

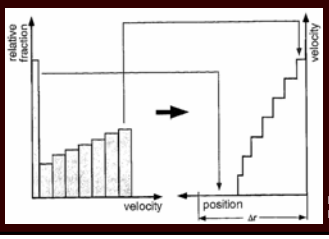
Preliminary results



low WSS high WSS

WSS: Future work

- Compensate flow enhancement
- Use more elaborate model to find dv/dr from distributions



Frayne 1995
MRM 34:376

Clinical applications

- ☑ Coronary flow
- ☑ Wall-shear stress in carotids
- ***Cardiac output***

Cardiac output & stroke volume

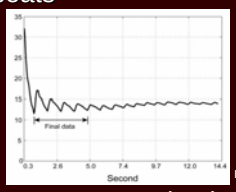
- Cardiac output:
  - Total volume ejected by heart per minute
  - L/min
- Stroke volume:
  - Volume ejected by heart per heartbeat
  - ml

Cardiac output: Motivation

- Ischemia, valve disease & hypertension
- Peripheral resistance / blood pressure
- Monitoring of drug therapy
- Right ventricle
  - Lung chronic disease
  - Lung transplantation
- No non-invasive “gold standard”

CO measure with MRI

- Slow: averaged through a few heartbeats



Park 2006
MRM 56:432

- We propose measuring beat-to-beat stroke volume (real-time cardiac output)
  - “stroke volume variability”

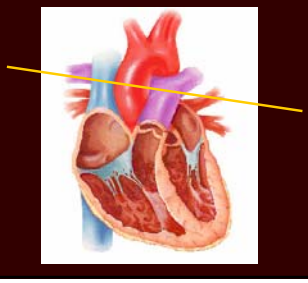
Beat-to-beat CO measurement

- Needs to be fast (real-time)
- Partial volume not a big issue
  - We only need an “average velocity” for each voxel
- Phase contrast ok

Spiral phase-contrast!!!

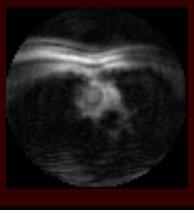
Slice prescription

- Perpendicular to aorta
- Before main bifurcations



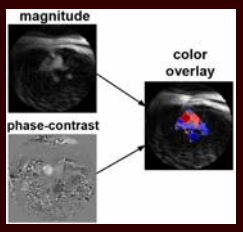
The big challenge

- Need a cross-sectional area estimate
- Area changes and moves
  - During RR: pulsatility
  - From one RR to the other: breathing



ROI prescription

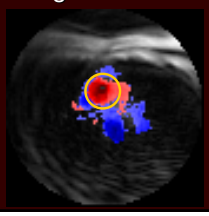
- Create color flow data



(show video)

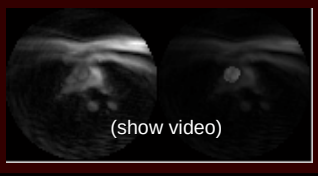
ROI prescription

- Projection: show highest velocity in each pixel throughout entire acquisition
- Draw ROI
- Inside ROI = eligible



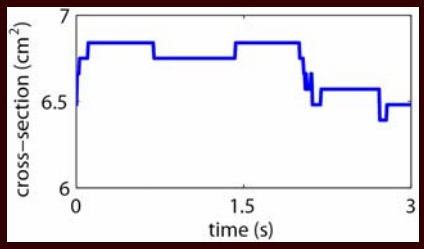
ROI following

- Criteria
  - Voxel is eligible
  - Velocity in voxel exceeds a threshold
- Time-window: ±1 second



Time-varying cross-section estimate

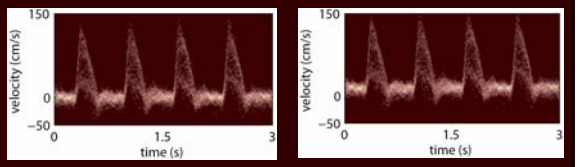
- Cross-sectional area = voxel area x #voxels



Velocity off-set correction

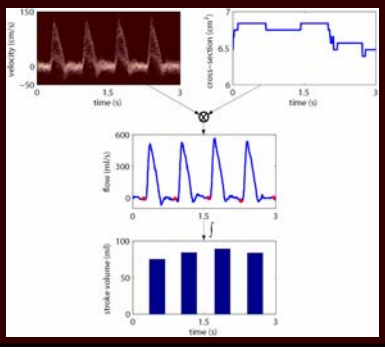
- Eddy currents → velocity off-set

True velocity histrogram **Measured histrogram**

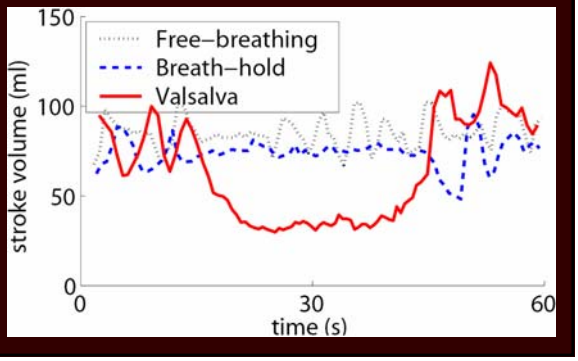


- Find “mode” of histogram and shift to zero

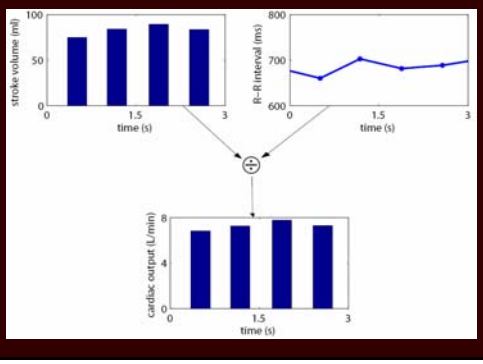
Stroke volume calculation



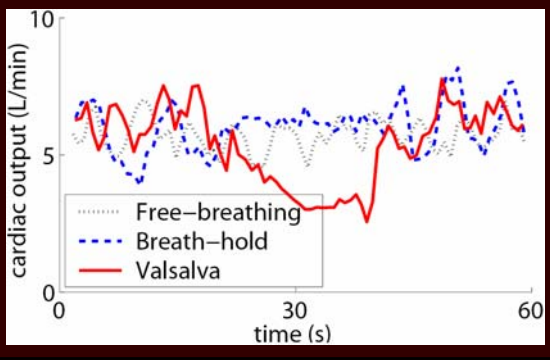
Stroke volume: Results



Cardiac output calculation



Cardiac output: Results



Cardiac output: Future work

- Acquire longer datasets (5 minutes)
- Try different stimuli
- Correlate S.V.V. and H.R.V.
  - S.V.V. analysis

Clinical applications

- ☑ Coronary flow
- ☑ Wall-shear stress in carotids
- ☑ Cardiac output

The End

Thank you!

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