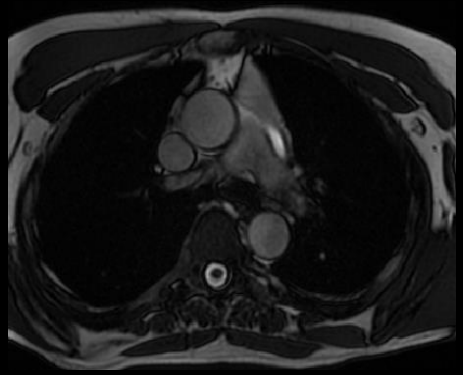
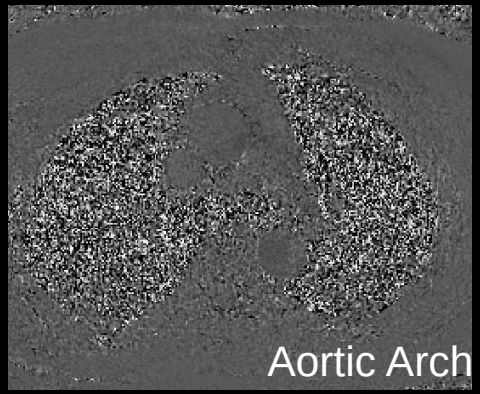
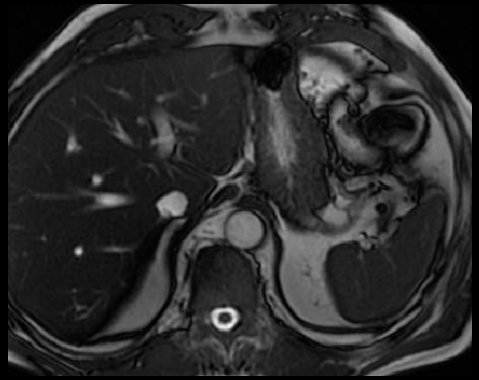
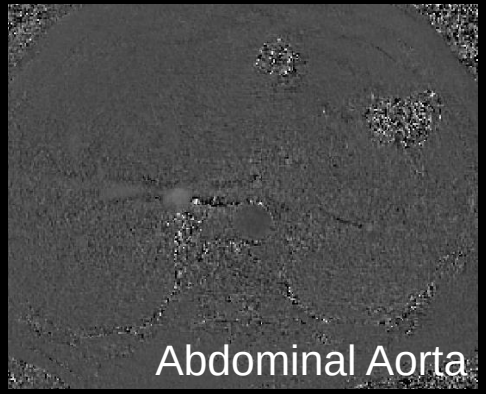
Free-Breathing Radial 2D Phase Contrast MRI for Aortic Pulse Wave Velocity Measurements in Healthy Older Adults









Grant S. Roberts[1]
Kevin M. Johnson[1,2]
Leonardo A. Rivera-Rivera[2]
Steven R. Kecskemeti[2]
Ozioma C. Okonkwo[3]
Laura B. Eisenmenger[2]
Oliver Wieben[1,2]

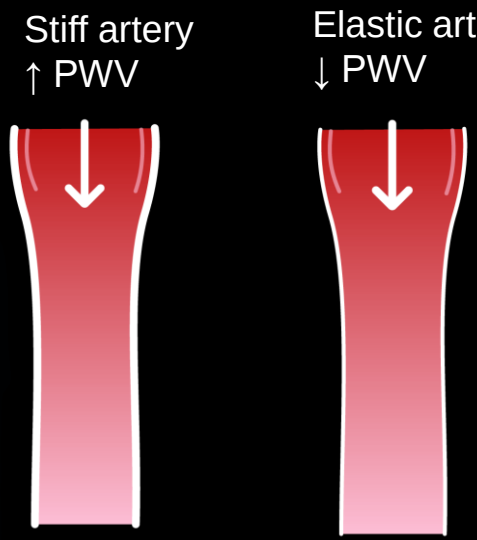
University of Wisconsin-Madison, Dept. of:

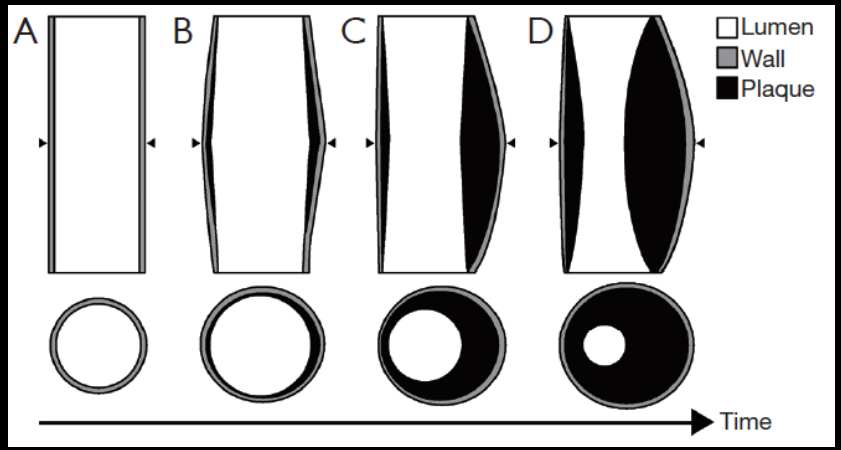
Medical Physics[1]
Radiology[2]
Medicine[3]

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON

Background: Pulse Wave Velocity (PWV)

- Pulse wave velocity (PWV)
  - Defined as the rate at which pulse pressure propagates through a vessel
  - Indirectly related to vessel stiffness[1]
  - Early indicator of CV disease



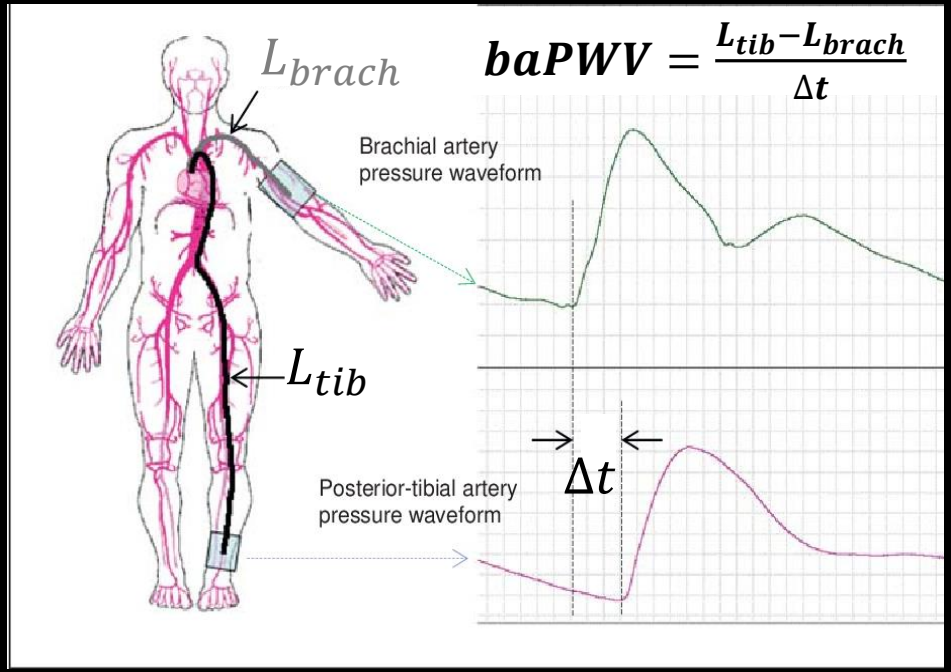


From: Wentland AL, et al. *Cardiovasc Diagn Ther*. 2014; 4(2):193–206

[1]Calvacante, JL, et al. *J Am Coll Cardiol*. 2011; 57:1511–22

Background: Pulse Wave Velocity (PWV)

- Many studies on PWV and CV disease incidence[2]
- Clinically assessed with applanation tonometry
  - Easy and inexpensive
  - Carotid-femoral (caPWV) or brachial-ankle (baPWV)
  - Distances are approximated
    - Leads to PWV error[3]



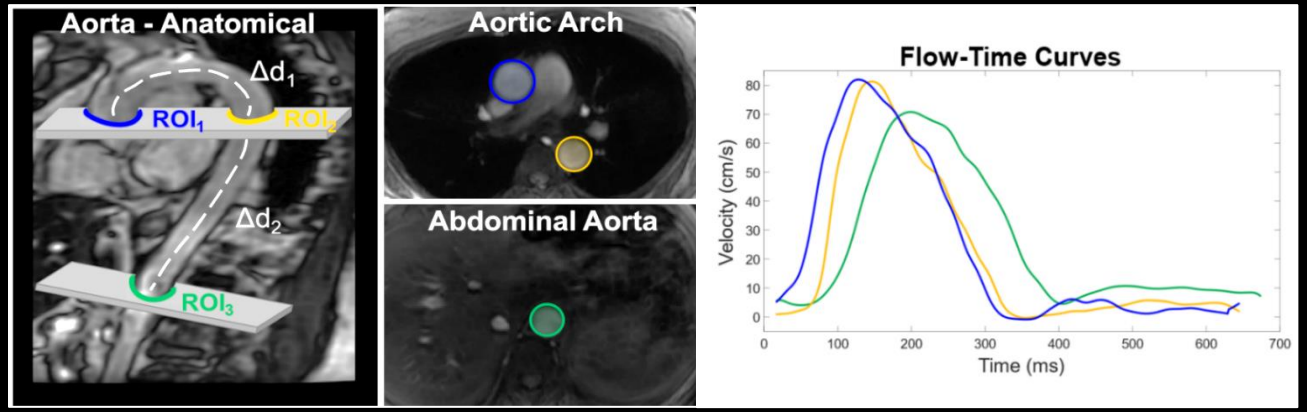
From: J Sugawara and H Tanaka. *Pulse (Basel)*. 2015; 3(2).

[2]Kim, HL, et al. *Front Cardiovasc Med*. 2019; 6(40).

[3]Rajzer, MW, et al. *J Hypertens*. 2008; 26(10):2001-07

Background: MRI-based PWV

- MR can also be used to assess PWV (usually aortic)
  - Often requires breath-holds (BHs)
  - **May be difficult/impossible for some patients**

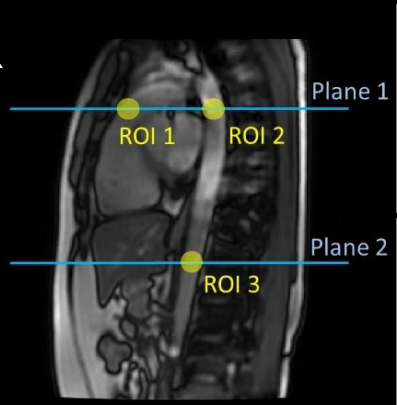


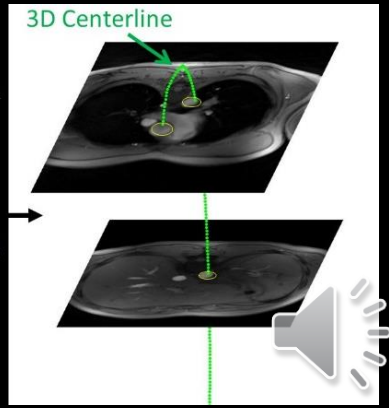
We present a method to measure aortic PWV using a free-breathing (FB) radial 2DPC sequence

Methods: Acquisition

- A radial FB 2DPC sequence was implemented and compared to a Cartesian BH 2DPC (GE) at 3T
  - Parameters matched
  - 18 subjects (13F, mean age=57y)
- 2 axial planes
  - Aortic arch and abdominal aorta
  - 3 ROI measurements total
- bSSFP images were acquired for aorta centerlines (scan time = 15s)

Parameter	Free-Breathing Radial	Breath-Held Cartesian
Scan time	2:27	0:13
Projections	10,000	N/A
# Frames	40	40
Slice Thickness	6 mm	6 mm
V_{enc}	150 cm/s	150 cm/s
Cardiac Gating	Retrosp. PG	Prosp. PG
Resp. Gating	Retrosp. Bellows	N/A
Spatial Res.	1.40 mm^2	1.41 mm^2
Temporal Res.	15-33 ms	15-33 ms





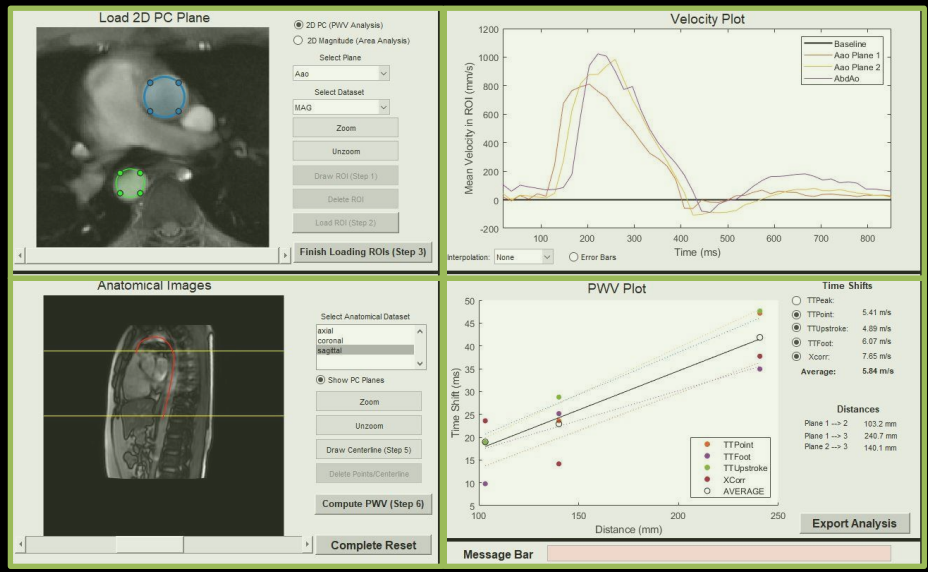
Methods: Sub-sampling + Local Low Rank Reconstruction

- Radial scans were retrospectively subsampled to 2,500 projections
  - Corresponding to 0:37 scan time
- A local low rank reconstruction was used to improve image quality

$$\hat{\mathbf{x}} = min_{\mathbf{x}} \left[\|\mathbf{A}\mathbf{x} - \mathbf{k}\|_2^2 + \sum \lambda_b \|\mathbf{R}_b\mathbf{x}\|_* \right]$$

Methods: Post-Processing

- Circular ROIs manually drawn around vessels (3 measurements total)
  - Flow waveforms smoothed with Gaussian filter
- TT-foot, TT-upstroke, TT-point, and cross-corr. methods were used[4]
- Centerlines drawn manually from the bSSFP and fit to a 3D b-spline
- Measured time shifts were plotted against centerline distances
  - Linear regression was used to fit the 3 data points
  - Inverse of the fitted slope is PWV

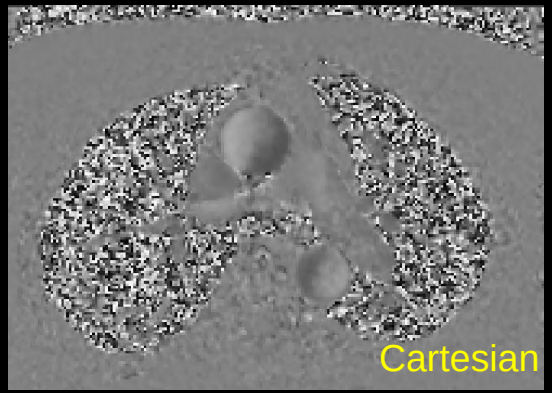


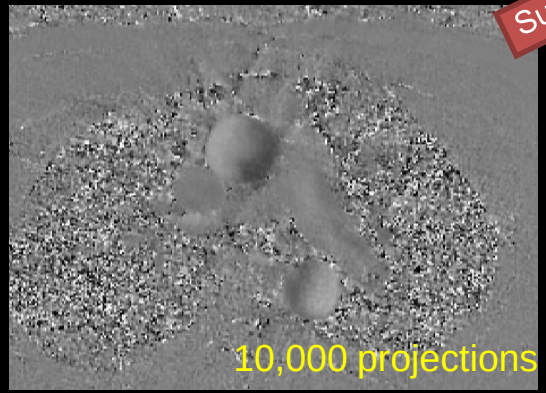
[4]Dogui, A, et al. *J Magn Reson.* 2011; 33:1321-29

Results: Local Low Rank Reconstruction

- Local low rank reconstruction mitigated undersampling artifacts

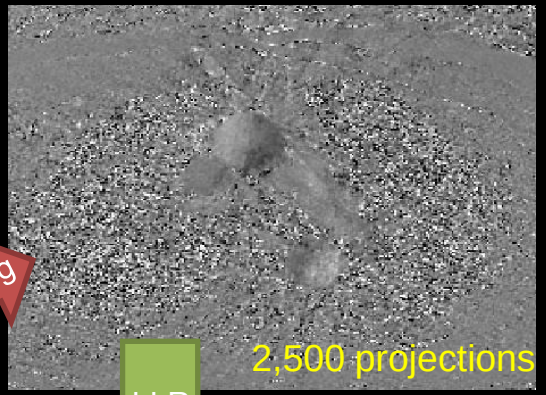
Fully-sampled



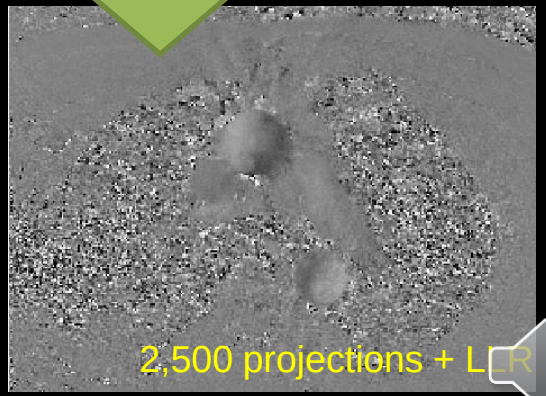


Subsampling

Sub-sampled



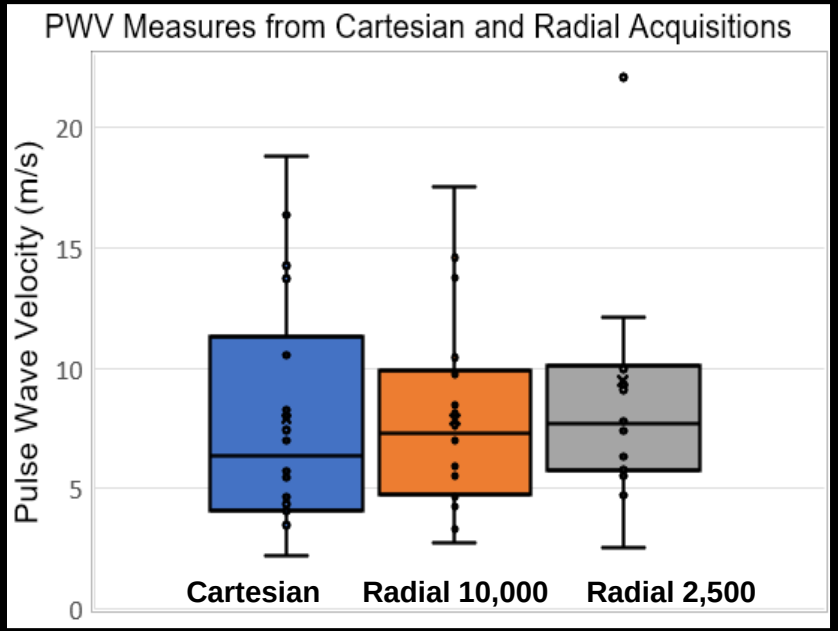
LLR



Results: Radial vs. Cartesian

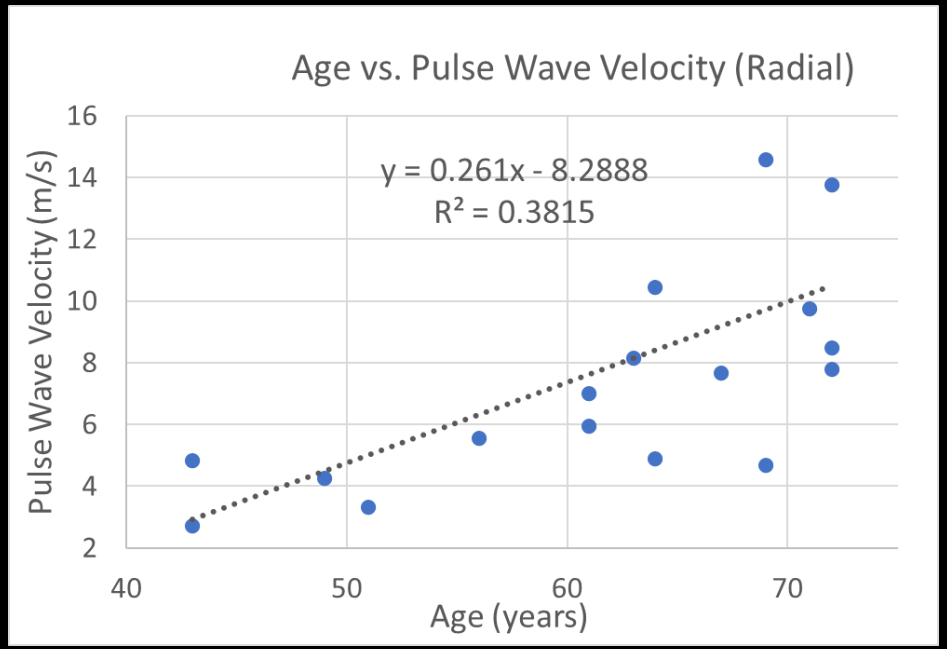
- No significant differences between FB radial and BH Cartesian
  - 10,00 radial → Cartesian: p=0.58
  - 2,500 radial → Cartesian: p=0.97
- No significant differences in variance were found (all p>0.4)

- Mean PWV (±standard deviation) for each acquisition are:
  - BH Cartesian: 7.90 ± 4.88 m/s
  - FB Radial (10,000): 7.85 ± 4.07 m/s
  - FB Radial (2,500): 9.46 ± 6.03 m/s



Results: Radial vs. Cartesian

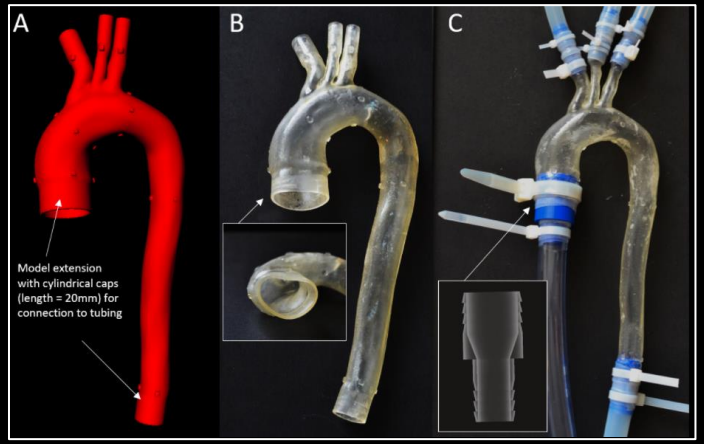
- Moderate, positive correlation between age and aortic PWV
- Other studies have demonstrated this relationship[5]



[5]Rogers, WJ, et al. *JACC.* 2001; 38(4):1123-29

Discussion

- FB PWV measures were comparable to BH Cartesian PC scans
  - Demonstrates feasibility of FB acquisitions for PWV assessment
- Useful for PWV assessment in populations with breath-hold difficulty
- Local low rank reconstructions can be used to reduce scan time, improve image quality, or increase temporal resolution
- Validation studies are needed to compare acquisitions to ground-truth



From: Zimmerman, J, et al. *Proc Intl Soc Mag Reson. Med 28.* 2020; #2280.

Acknowledgements

UW CVMR Team:
Oliver Wieben, PhD
Laura Eisenmenger, MD
Kevin Johnson, PhD
Leonardo Rivera-Rivera, PhD
Carson Hoffman, PhD
Phillip Corrado, MS
Dan Seiter, MS
Ruiming Chen, BS
Alexander Niver, BS
Alma Spahic, BS
Archana Dhyani

Okonkwo Lab:
Ozioma Okonkwo, MD
Sarah Lose, MS
Alexandri Moellner, MPH

Waisman Center:
Steve Kecskemeti, PhD
Ronald Fisher, BS

Financial Support: We receive financial and research support from GE Healthcare.