

# MRI Measurement of the Aorta in MESA

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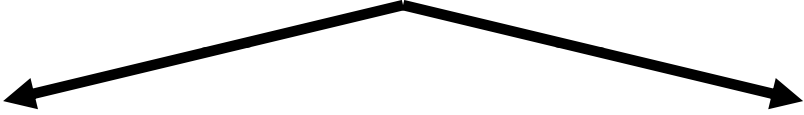
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**Jang-Young Kim, MD, Yoshiaki Ohyama, MD**

# Introduction for Dataset

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## Thoracic Aorta Imaging



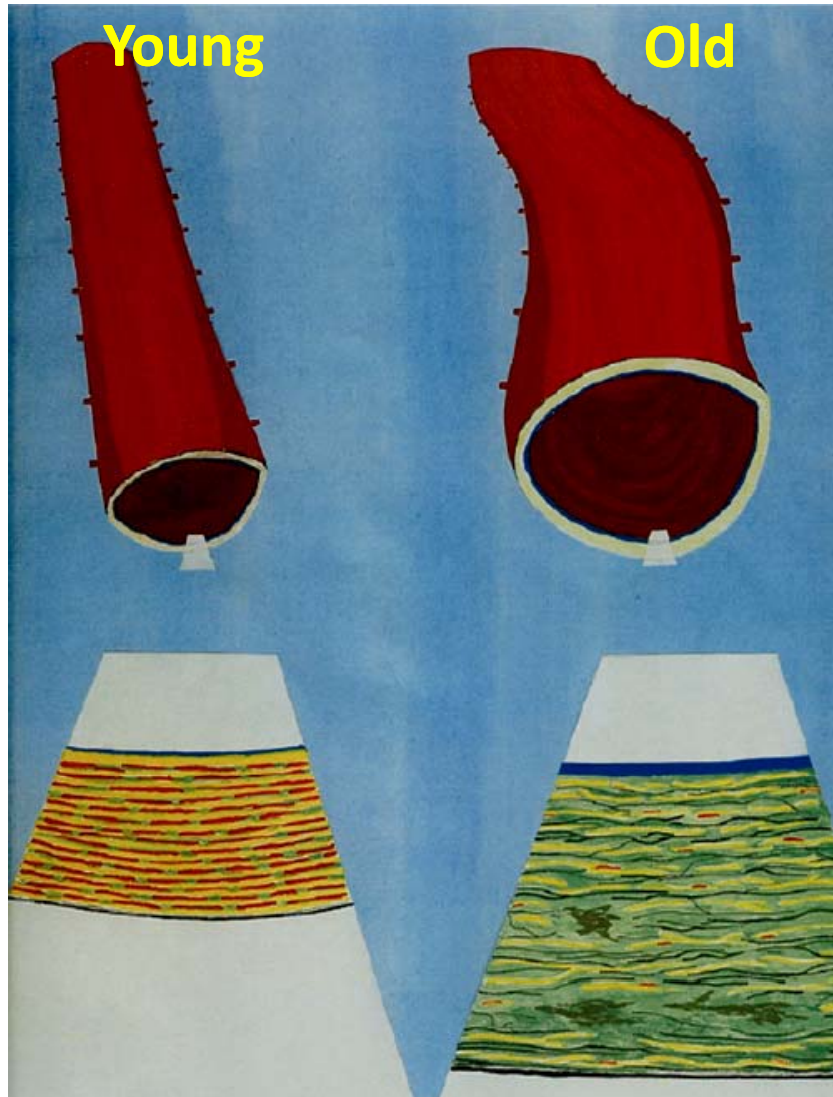
### Structure

- Wall thickness and lumen size
- Calcifications

### Function

- Ao distensibility
- Pulse wave velocity (PWV)
- Arterial Stiffness

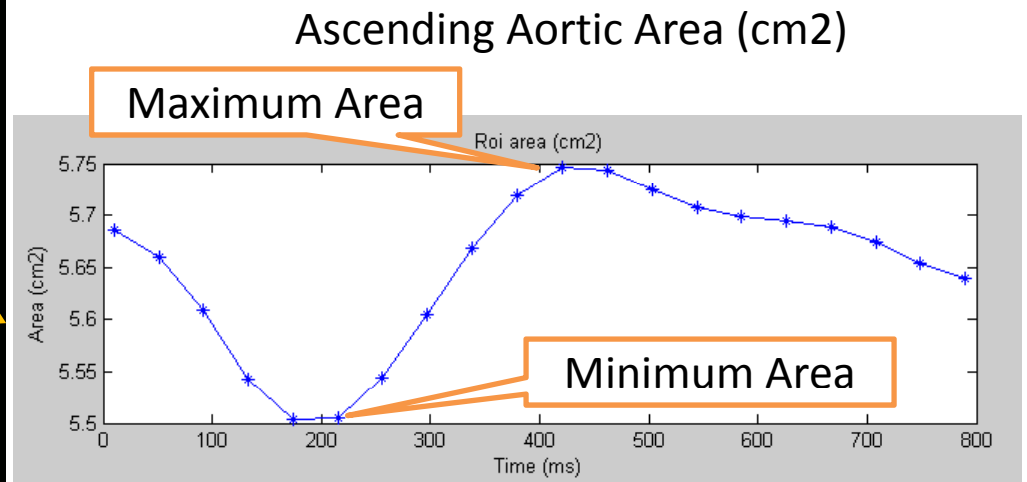
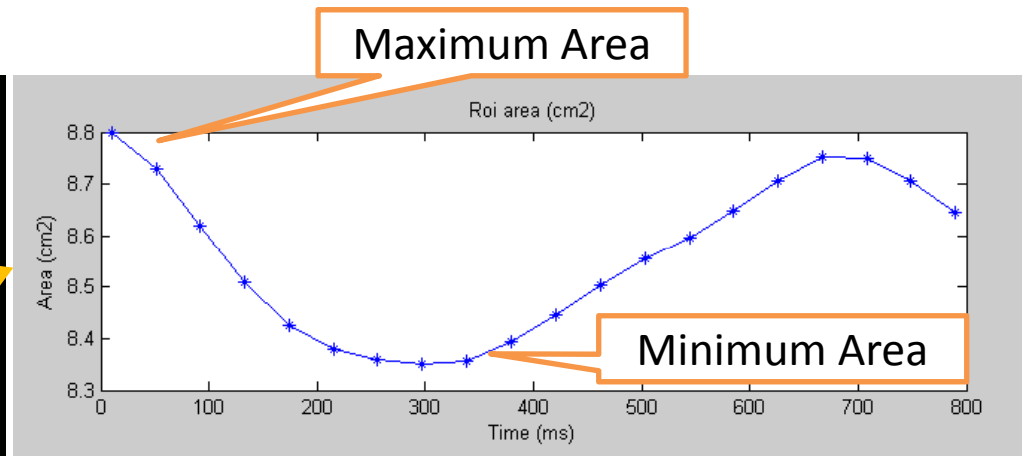
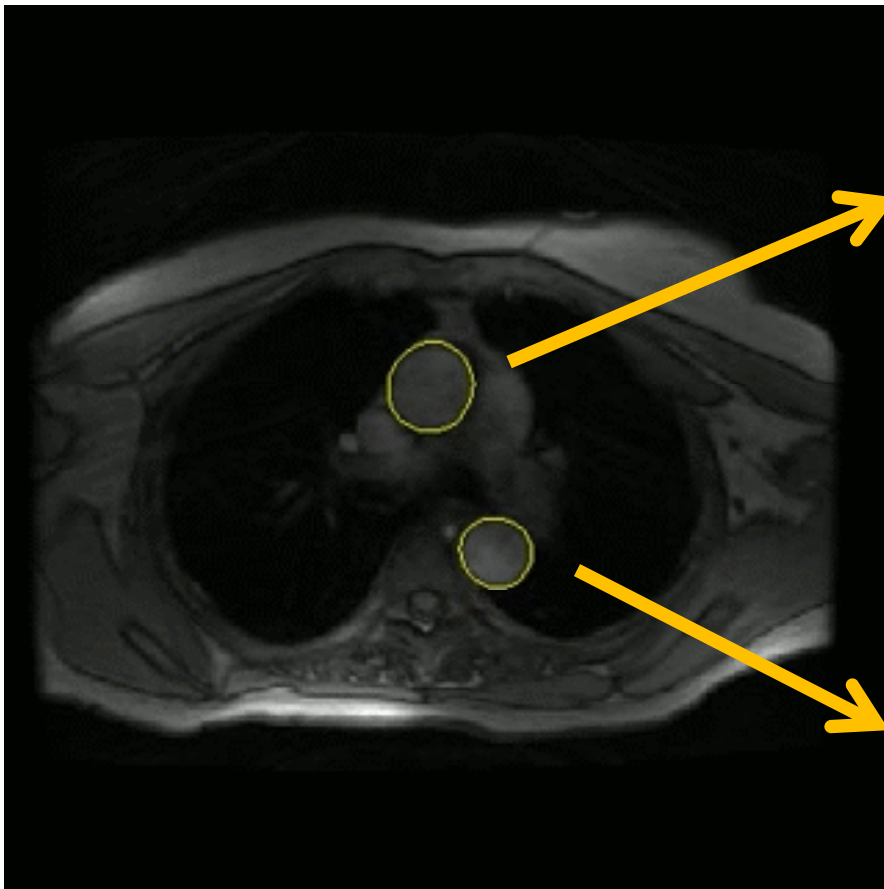
# Structural Change of Ao



- Lumen ↑
- Thickness ↑

Yellow: elastic lamellae  
Black: collagen fibers  
Green: mucoid material  
Red: muscle

# Aortic Strain by ARTFUN Software in MR



Descending Aortic Area (cm2)

# Aortic Distensibility

$$\begin{aligned}
 \text{Distensibility} &= \Delta V / V \cdot \Delta P \\
 &= \Delta A / A \cdot PP \\
 &= \frac{(D_s^2 - D_d^2)}{D_d^2 \cdot PP}
 \end{aligned}$$

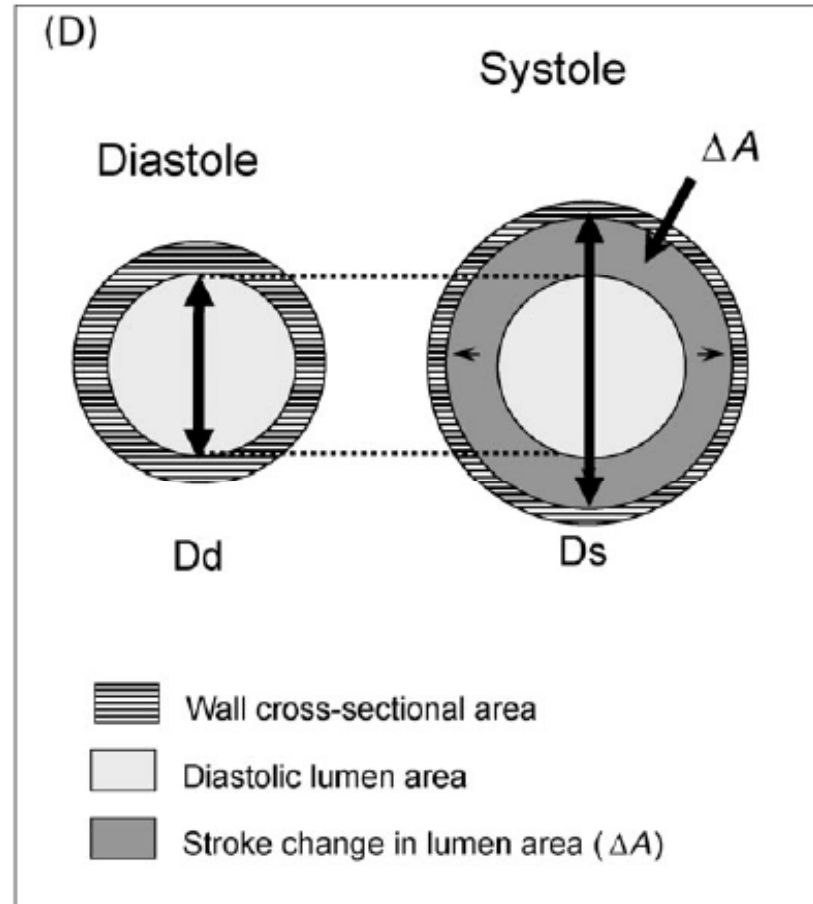
PP ; Pulse Pressure

$$\left\{ \text{Strain} = \frac{(D_s^2 - D_d^2)}{D_d^2} \right\}$$

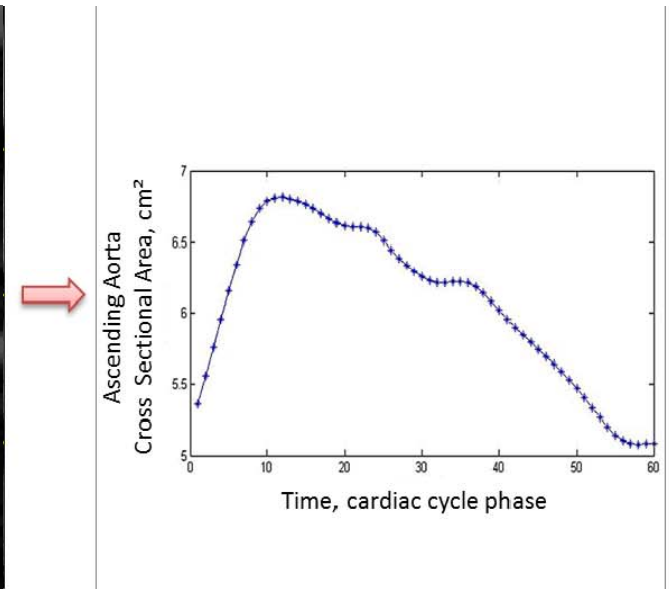
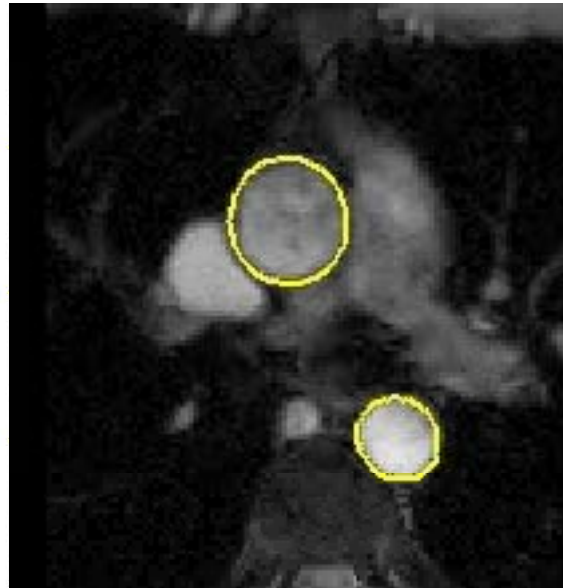
**Aortic Stiffness ↑**



**Aortic distensibility ↓**



# Aortic Distensibility in MRI



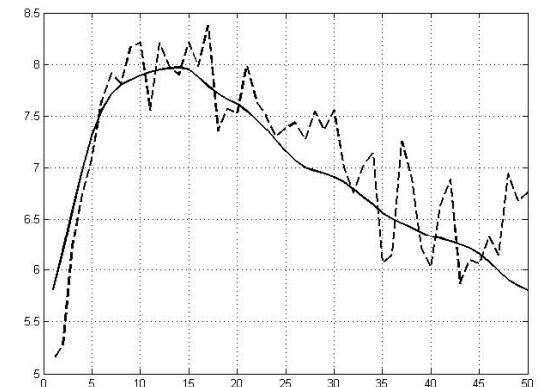
## Validation

- Flow phantom
- Theoretical Bramwell-Hill model
- Stiffness, age / cohorts

## Interobserver variations (SSFP)

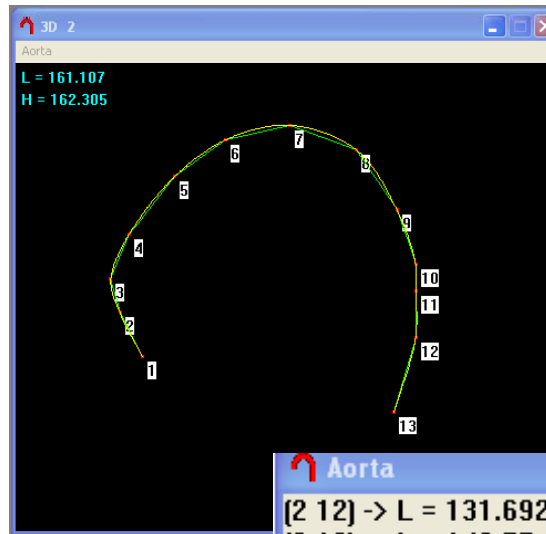
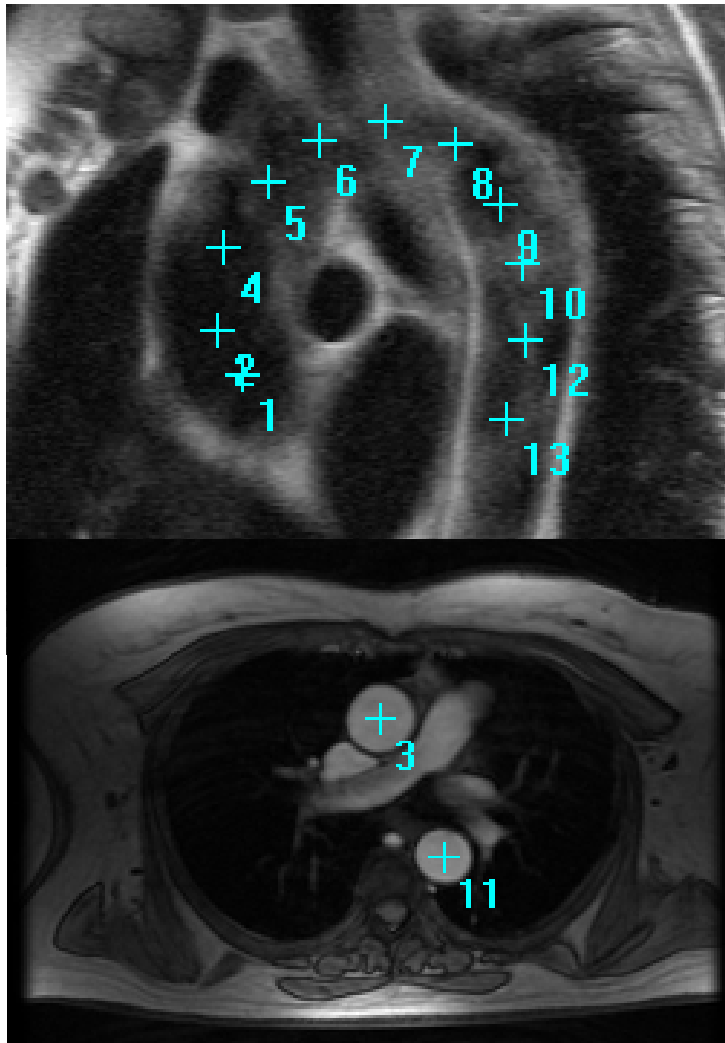
AA Area : 6 mm<sup>2</sup> (39) vs. 560 mm<sup>2</sup>

AA Strain: 1% (8) vs. 18% (12%)



# Aortic Pulse Wave Velocity (PWV) by ARTFUN Software in MR

Distance( $\Delta d$ )

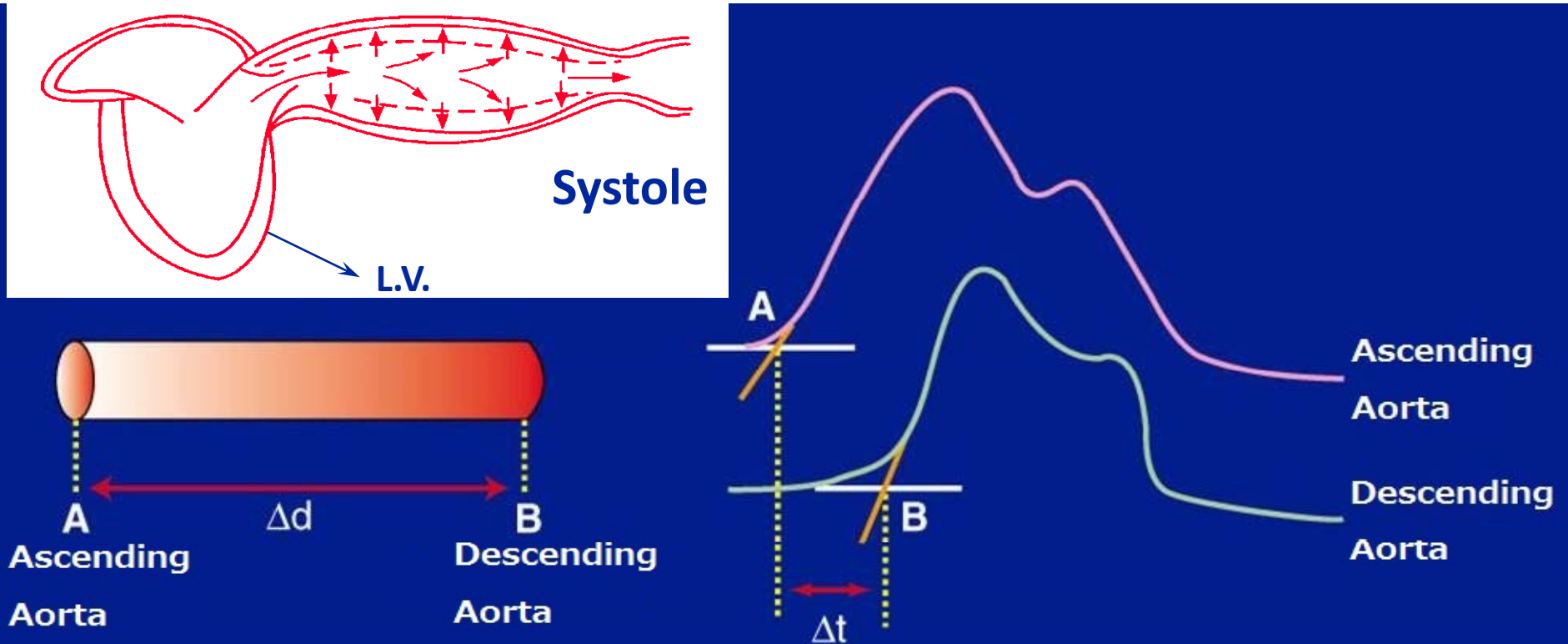


| Aorta     |                          |
|-----------|--------------------------|
| [2 12] -> | L = 131.692, H = 132.81  |
| [2 13] -> | L = 149.77, H = 150.913  |
| [3 4] ->  | L = 11.391, H = 11.5757  |
| [3 5] ->  | L = 28.5565, H = 28.8358 |
| [3 6] ->  | L = 43.0518, H = 43.4003 |
| [3 7] ->  | L = 58.4083, H = 58.9053 |
| [3 8] ->  | L = 74.6412, H = 75.3638 |
| [3 9] ->  | L = 91.2356, H = 92.097  |
| [3 10] -> | L = 104.815, H = 105.732 |
| [3 11] -> | L = 111.263, H = 112.2   |
| [3 12] -> | L = 121.886, H = 122.852 |
| [3 13] -> | L = 139.963, H = 140.955 |
| [4 5] ->  | L = 17.1655, H = 17.2601 |
| [4 6] ->  | L = 31.6608, H = 31.8246 |
| [4 7] ->  | L = 47.0173, H = 47.3296 |
| [4 8] ->  | L = 63.2502, H = 63.7881 |

(Unit: mm)



# Pulse Wave Velocity (PWV): Gold standard of arterial stiffness



$$\text{PWV} = \text{Distance}(\Delta d) / \text{Time delay}(\Delta t) \quad (\text{unit: m/sec})$$

Usually measured on 10 heartbeats  
PWV = pulse wave velocity

# Functional Change of Ao

Young normal aorta



Higher distensibility, lower PWV

Resistance  
artery

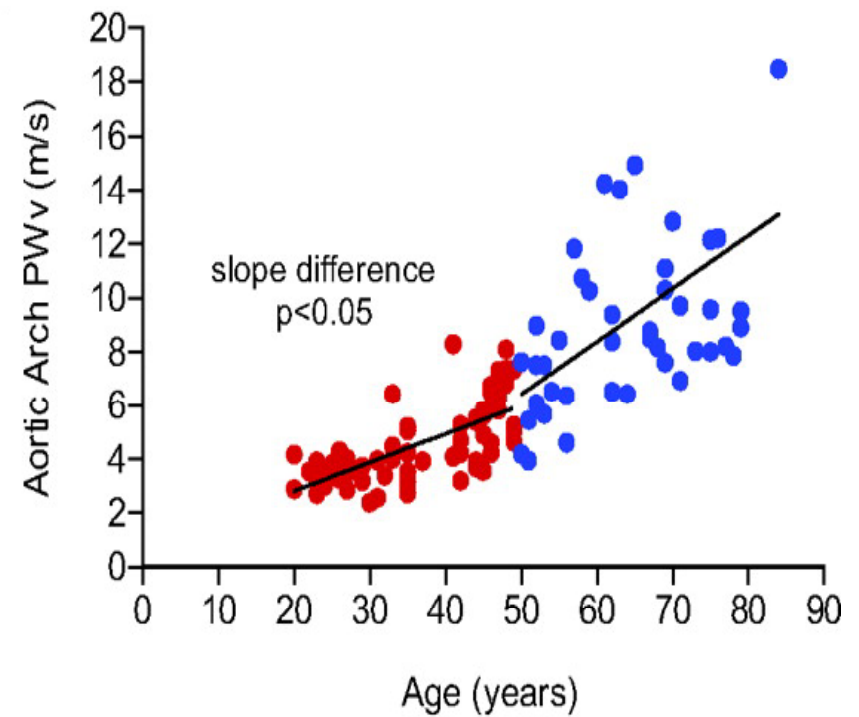
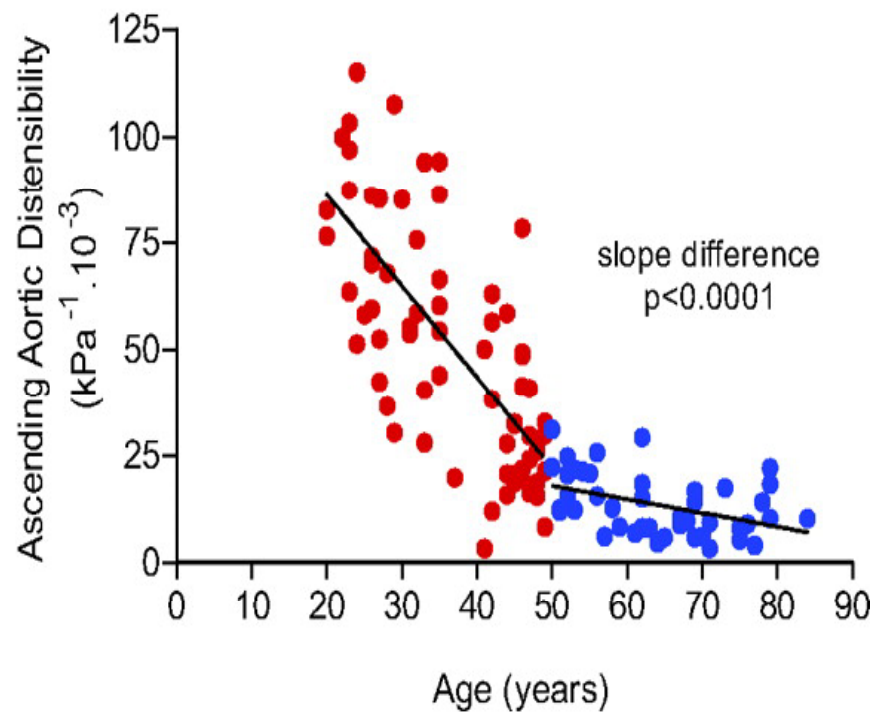
Old stiff aorta



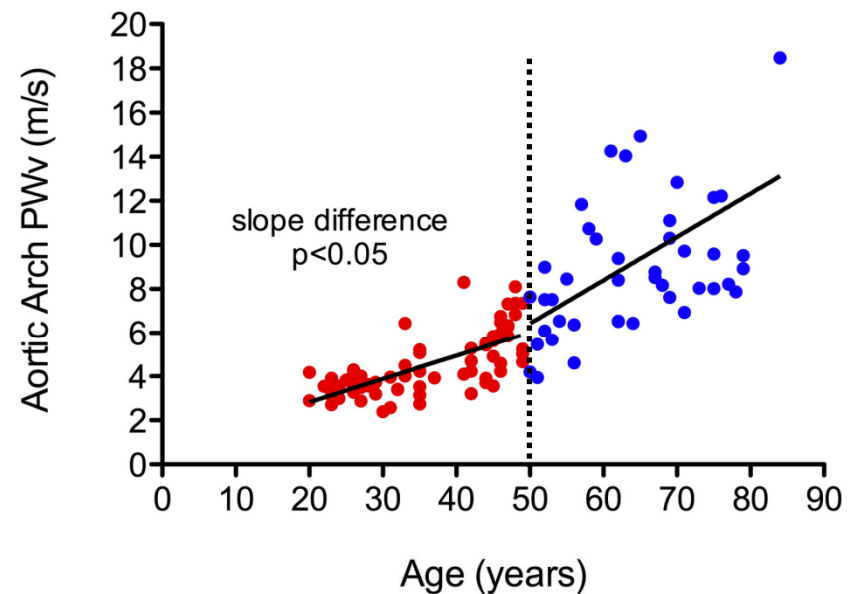
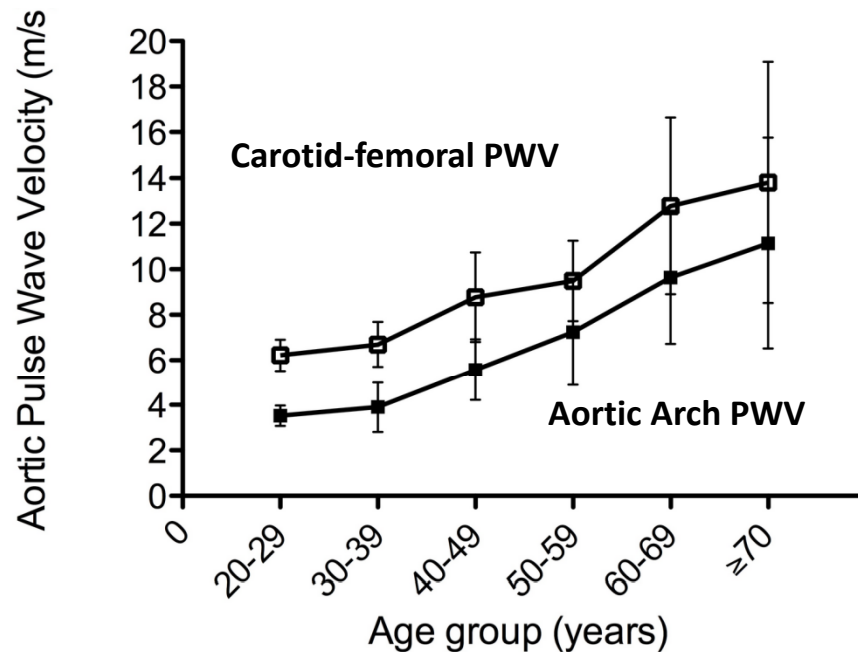
Lower distensibility, higher PWV

Resistance  
artery

# Vascular Aging of MRI-Derived Aortic Function



# PWV by US and MRI



- Overestimation of vessel length with surface measurement
- Exclusion of the ascending aorta with (low PWV) and inclusion of peripheral arteries (high PWV)

Redheuil A. Yu W et al. Hypertension 2010

# MRI Variables for Aortic Studies

(Measured by ARTFUN software)

| Variable Name     | Variable Label                                 | Units           |
|-------------------|------------------------------------------------|-----------------|
| MAX_ASCAO         | Area of maximum ascending aorta                | cm <sup>2</sup> |
| MIN_ASCAO         | Area of minimum ascending aorta                | cm <sup>2</sup> |
| MAX_DESCAO        | Area of maximum descending aorta               | cm <sup>2</sup> |
| MIN_DESCAO        | Area of minimum descending aorta               | cm <sup>2</sup> |
| DIFT_ASCDESC      | Slope for PWV calculation                      |                 |
| DIST_ASCDESC(H)   | Distance of aortic arch                        |                 |
| Strain_ASCAO_Per  | Strain of ascending aorta                      | %               |
| Strain_DESCAO_Per | Strain of descending aorta                     | %               |
| PWV               | Pulse wave velocity                            | m/sec           |
| AorticDisten      | Aortic distensibility (needs to be calculated) |                 |

# Descriptive Statistics for MESA 5 (N=2,125)

|                    | n     | Mean $\pm$ SD    | Median | Range (min-max) |
|--------------------|-------|------------------|--------|-----------------|
| MAX_ASCAO          | 2,123 | 9.3 $\pm$ 2.3    | 9.0    | 3.7-28.8        |
| MIN_ASCAO          | 2,123 | 8.5 $\pm$ 2.2    | 8.2    | 2.8-28.1        |
| MAX_DESCAO         | 2,056 | 5.5 $\pm$ 1.5    | 5.4    | 2.0-16.1        |
| MIN_DESCAO         | 2,056 | 4.9 $\pm$ 1.4    | 4.8    | 1.6-14.2        |
| DIFT_ASCDESC       | 2,046 | 16.9 $\pm$ 5.5   | 17.0   | 3.0-52.0        |
| DIST_ASCDESC (H)   | 2,078 | 132.7 $\pm$ 21.8 | 131.3  | 78.0-275.4      |
| Strain ASCAO (%)   | 2,123 | 10.0 $\pm$ 6.3   | 8.3    | 0.3-44.0        |
| Strain DESC AO (%) | 2,056 | 13.0 $\pm$ 8.4   | 10.7   | 1.2-56.0        |
| PWV                | 2,030 | 8.9 $\pm$ 4.2    | 7.9    | 2.6-41.7        |

# Structural Change of Ao (MESA)

Table 4

Ascending Aortic Luminal Diameter by Age and Gender in MESA Participants Without Influential Risk Factors<sup>a</sup> (N = 1612)

| Women                                          |     |                            |        |                             |      |      |
|------------------------------------------------|-----|----------------------------|--------|-----------------------------|------|------|
| Average ascending aortic luminal diameter (mm) |     |                            |        |                             |      |      |
| Age categories (years)                         | N   | 5 <sup>th</sup> percentile | Median | 95 <sup>th</sup> percentile | Min  | Max  |
| 45–54                                          | 416 | 24.6                       | 28.8   | 34.4                        | 17.8 | 37.7 |
| 55–64                                          | 232 | 25.7                       | 30.1   | 36.4                        | 23.7 | 40.5 |
| 65–74                                          | 157 | 26.1                       | 30.6   | 36.3                        | 24.2 | 40.0 |
| 75–84                                          | 37  | 26.8                       | 31.1   | 37.1                        | 26.7 | 37.2 |

| Men                                            |     |                            |        |                             |      |      |
|------------------------------------------------|-----|----------------------------|--------|-----------------------------|------|------|
| Average ascending aortic luminal diameter (mm) |     |                            |        |                             |      |      |
| Age categories (years)                         | N   | 5 <sup>th</sup> percentile | Median | 95 <sup>th</sup> percentile | Min  | Max  |
| 45–54                                          | 345 | 27.2                       | 31.6   | 37.3                        | 25.2 | 44.6 |
| 55–64                                          | 229 | 28.1                       | 32.8   | 40.7                        | 24.4 | 49.8 |
| 65–74                                          | 139 | 28.7                       | 34.2   | 41.0                        | 27.8 | 43.9 |
| 75–84                                          | 57  | 28.6                       | 34.7   | 40.8                        | 27.7 | 43.5 |

<sup>a</sup>Participants with hypertension, diabetes, lipid medication use, coronary calcium score value > 95<sup>th</sup> percentile and total cholesterol value > 95<sup>th</sup> percentile were excluded.

BSA: body surface area.

# Structural Change of Ao (MESA)

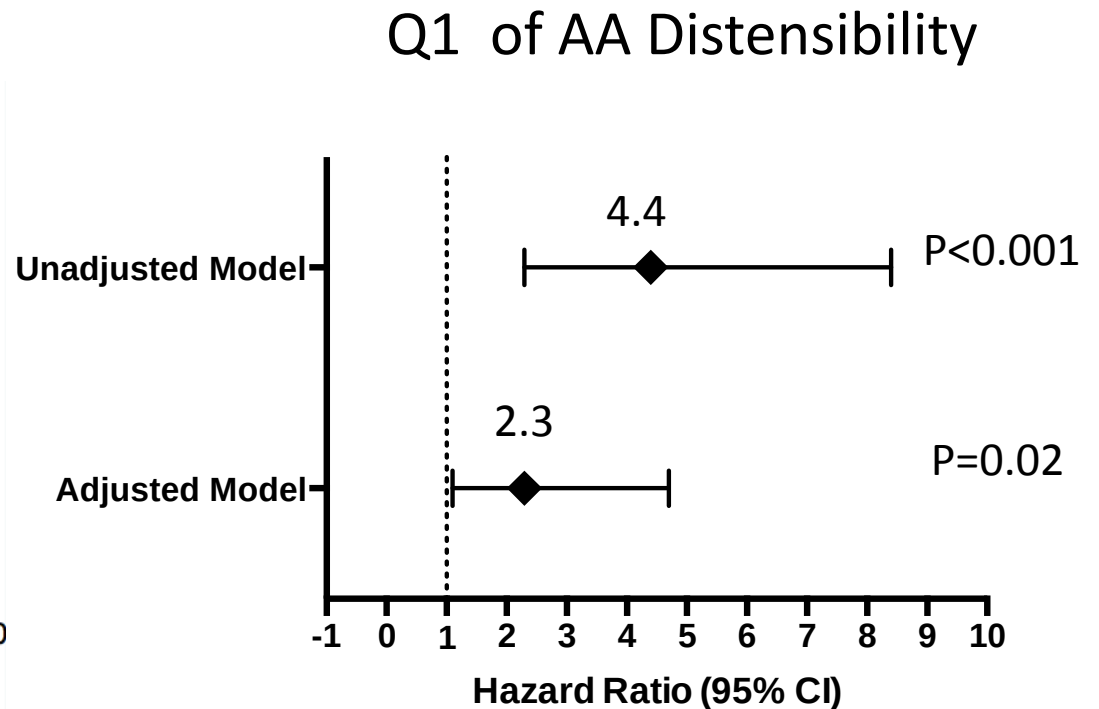
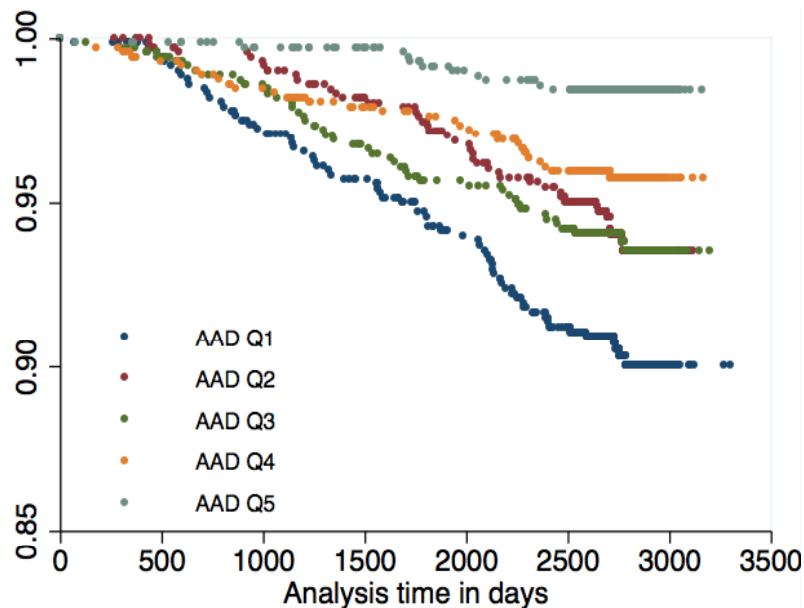
Table 3

Fully Adjusted Linear Regression Model Showing Associations of Ascending Aortic Luminal Diameter With Cardiovascular Disease Risk Factors in 3573 MESA Participants, 2000–2002

| Variable                                           | Regression coefficient (mm) | 95% CI      | P      |
|----------------------------------------------------|-----------------------------|-------------|--------|
| Age (per SD of 10 yrs)                             | 1.1                         | 1.0–1.3     | <0.001 |
| Gender                                             | 1.2                         | 0.9–1.5     | <0.001 |
| Body surface area (per SD of 0.23 m <sup>2</sup> ) | 1.2                         | 1.0–1.4     | <0.001 |
| Race                                               | 1.5                         | 1.1–1.9     | <0.001 |
| Chinese American                                   | −0.5                        | −0.8 - −0.2 | <0.001 |
| African American                                   | 0.03                        | −0.3 - 0.4  | 0.86   |
| Hispanic                                           |                             |             |        |
| Diastolic blood pressure (per SD of 10 mmHg)       | 0.73                        | 0.6–0.8     | <0.001 |
| Hypertension medication (yes)                      | 0.6                         | 0.4–0.9     | <0.001 |
| Cigarette smoking (yes)                            | −0.04                       | −0.3–0.2    | 0.74   |
| Diabetes                                           | −0.5                        | −0.9 - −0.2 | 0.006  |
| Total cholesterol (per SD of 36 mg/dL)             | −0.2                        | −0.3 - −0.0 | 0.007  |
| HDL (per SD of 15 mg/dL)                           | 0.1                         | −0.0–0.2    | 0.07   |
| Lipid medication (yes)                             | −0.7                        | −1.0 - −0.4 | <0.001 |
| IL-6 (per SD of 1.22 pg/mL)                        | 0.0                         | −0.1–0.1    | 0.98   |
| CRP (per SD of 6 mg/L)                             | −0.1                        | −0.2–0.0    | 0.07   |
| Max CCA IMT (per SD of 0.19 mm)                    | 0.09                        | −0.1–0.2    | 0.23   |
| Log CAC (per SD of 2.52)                           | 0.07                        | 0.0–0.1     | 0.01   |



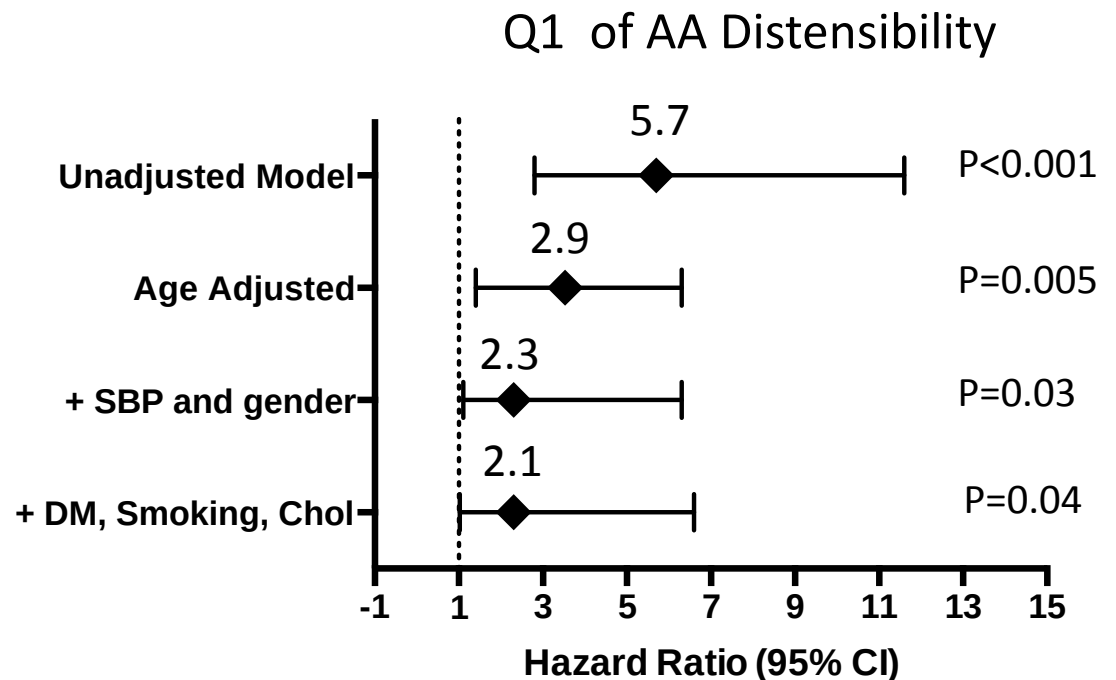
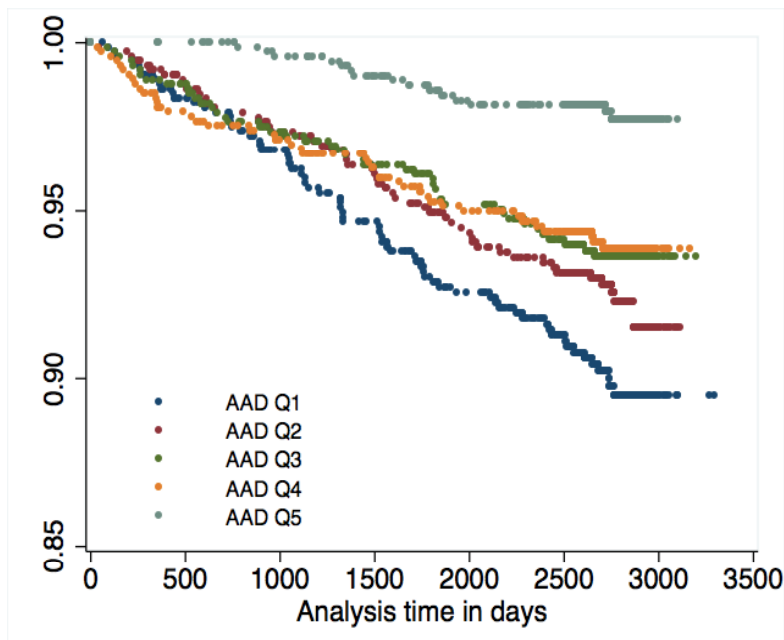
# Aortic Distensibility and Mortality



age, gender, ethnicity, BMI, smoking, SBP,  
HTN medication, diabetes



# Aortic Distensibility and Hard CVD



**No significant change when using MBP, PP or BP taken during MRI**  
**Remained significant after further adjustment for Carotid IMT, ABi, LV mass**

# Arterial Stiffness

- Main determinant of age-related systolic and pulse pressure increase
- Main predictor of stroke, myocardial infarction, and heart failure

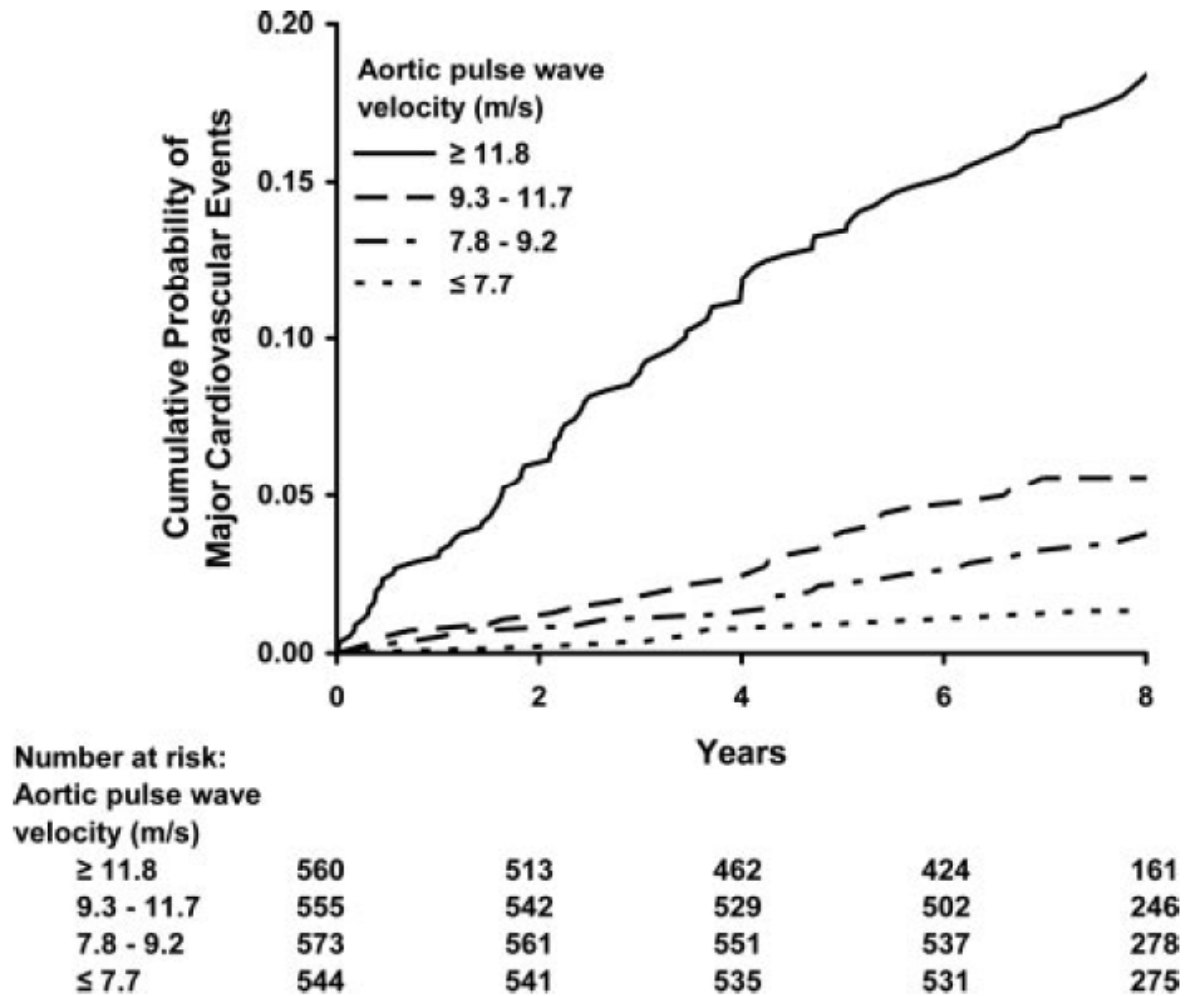
*Mattace-Raso FU et al. Circulation 2006;113:657-663*

*Ciannattasio C et al. JACC 2002;39:1275-1282*

*Boutouyrie P et al. Hypertension 2002;39:10-15*

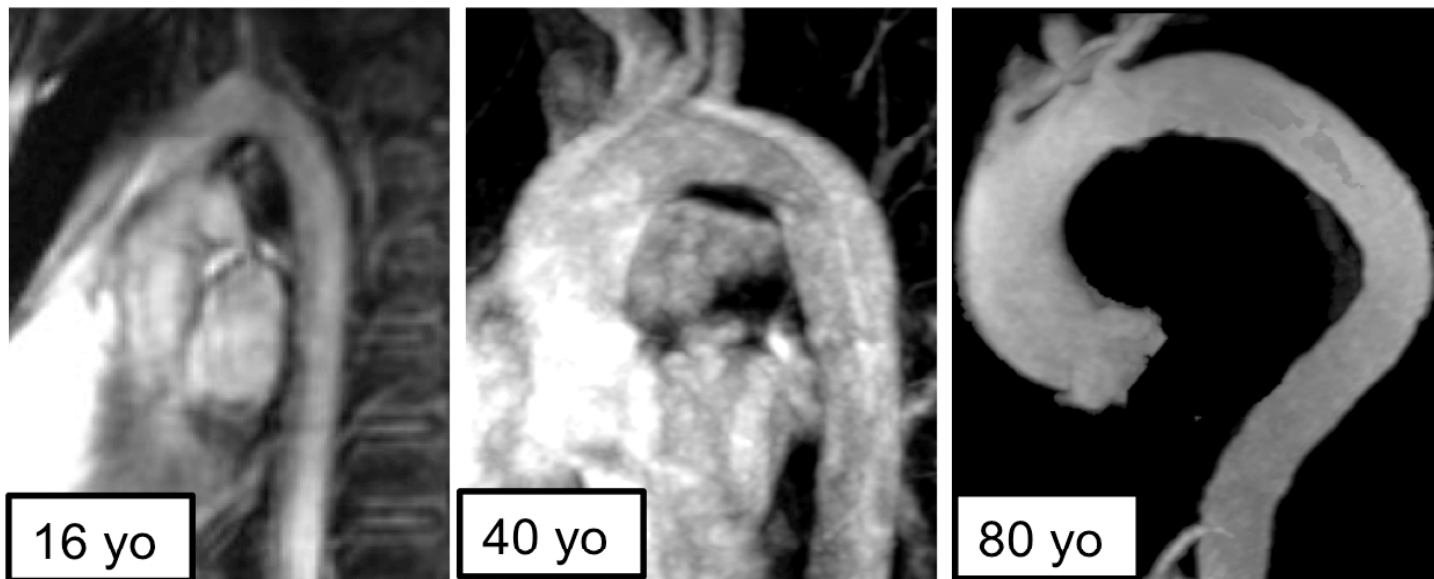
# Aorta stiffness and Cardiovascular Events

Framingham study, N=2232, 7.8years f/u



*Mitchell et al. Circulation 2010;120:505-511*

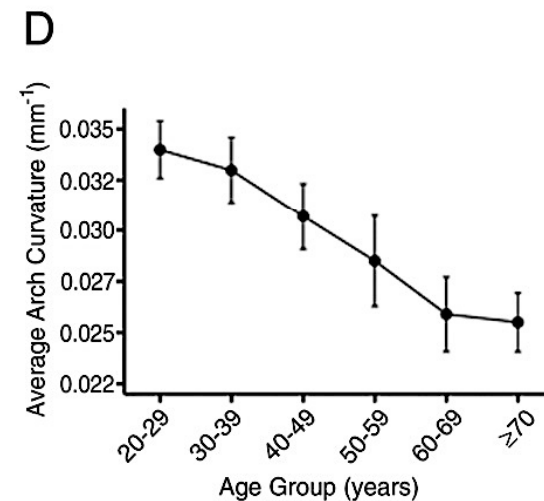
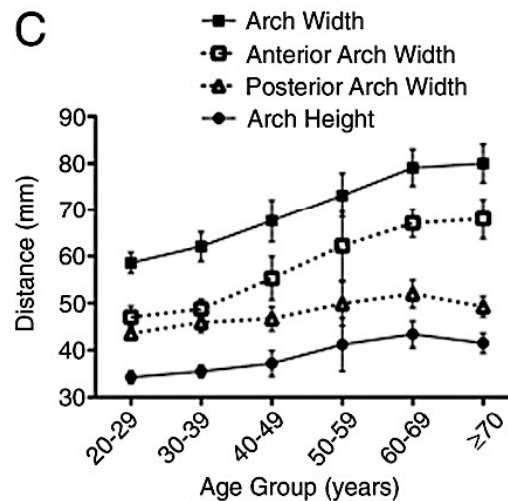
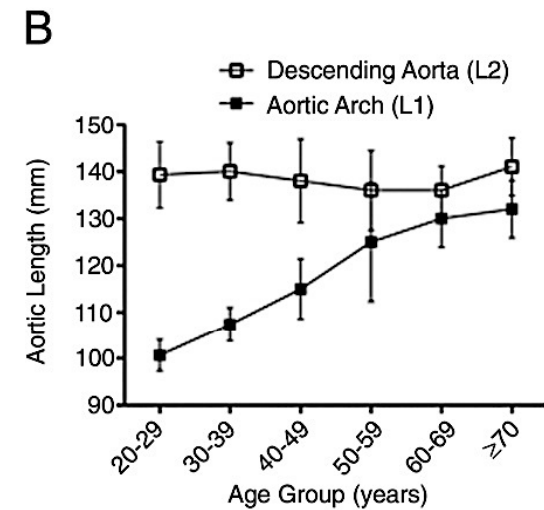
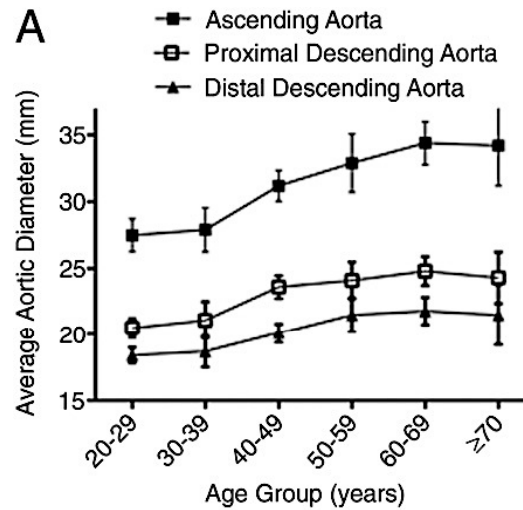
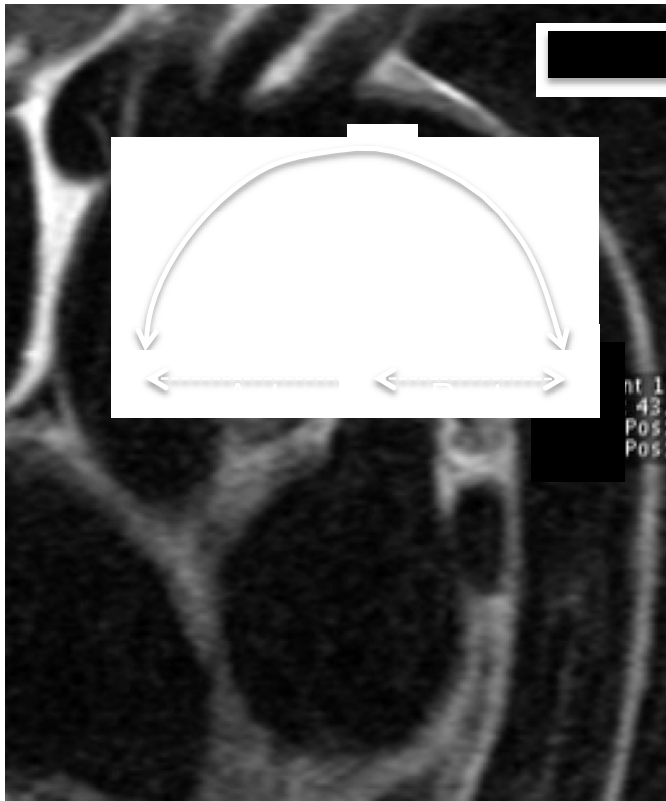
# Aortic Geometry and Aging



Sugawara et al. JACC Cvi 2008  
Hickson et al. JACC Cvi 2010

Redheuil et al. Artery Research 2014 in press

# Aortic Geometry and Aging

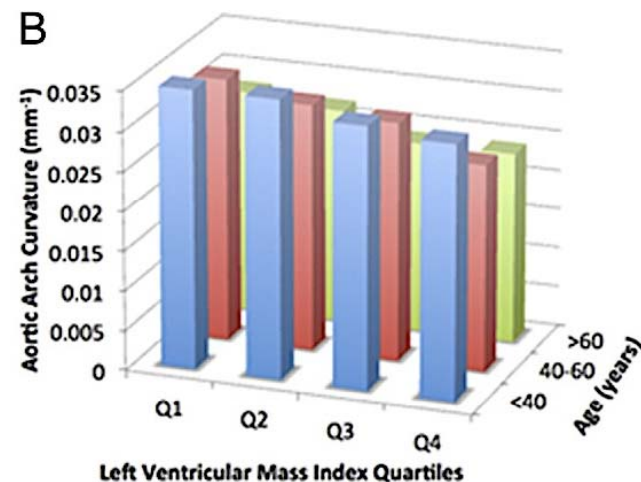
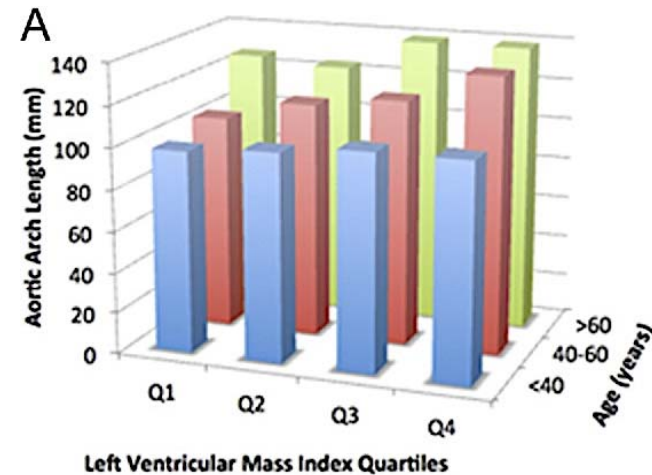


# Aortic Arch Geometry

## Blood Pressure and LV Remodeling

↑ SBP, DBP, PP  
independent of : age,  
gender, height, weight,  
hypertension, cholesterol,  
smoking

|                |              |             |
|----------------|--------------|-------------|
| *p<0.001       | Brachial SBP | Central SBP |
| AA Diameter    | R=0.61*      | R=0.62*     |
| Arch Length    | R=0.64*      | R=0.65*     |
| Arch Curvature | R=-0.71*     | R=-0.70*    |



Redheuil A. ,Yu, W et al. JACC 2011

# MESA Investigators

- Wake Forest University – G. Burke, G. Hundley, J. Carr
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  - University of Vermont – Russell Tracy and M. Cushman
- Tufts and U. Penn – J. Polak and Julio Chirinos



*Thank you*