2D Ultrasound Strain Measurements Can Quantify Relative Single-Plane Hoop Stress in an Abdominal Aortic Aneurysm Model

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Introduction:

Current size-based assessments of AAA rupture potential do not accurately identify all patients at risk, as diameter alone can not accurately assess real-time aortic tissue stress.

LaPlace Law:

$$Wall\ Tension = \frac{P_{TM} * Radius}{Wall\ Thickness}$$

True AAA rupture potential is related to :

- Hemodynamics Pressure
- Geometric Factors:
  - Vessel Diameter
  - Vessel Wall Thickness

Hypothesis:

2D ultrasound strain analysis, gated with real-time pressure, can quantify dynamic hoop stress, in a vessel phantom, at the specific location of maximum compliance mismatch.

Methods:

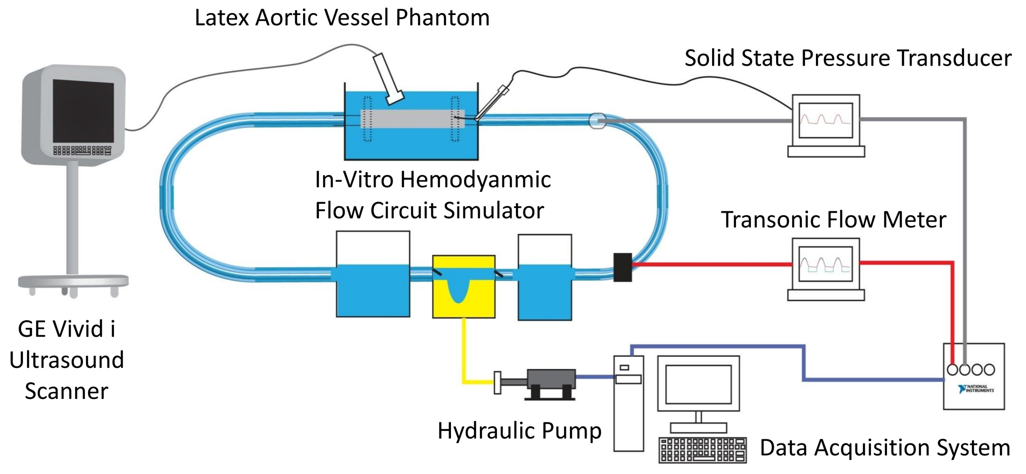
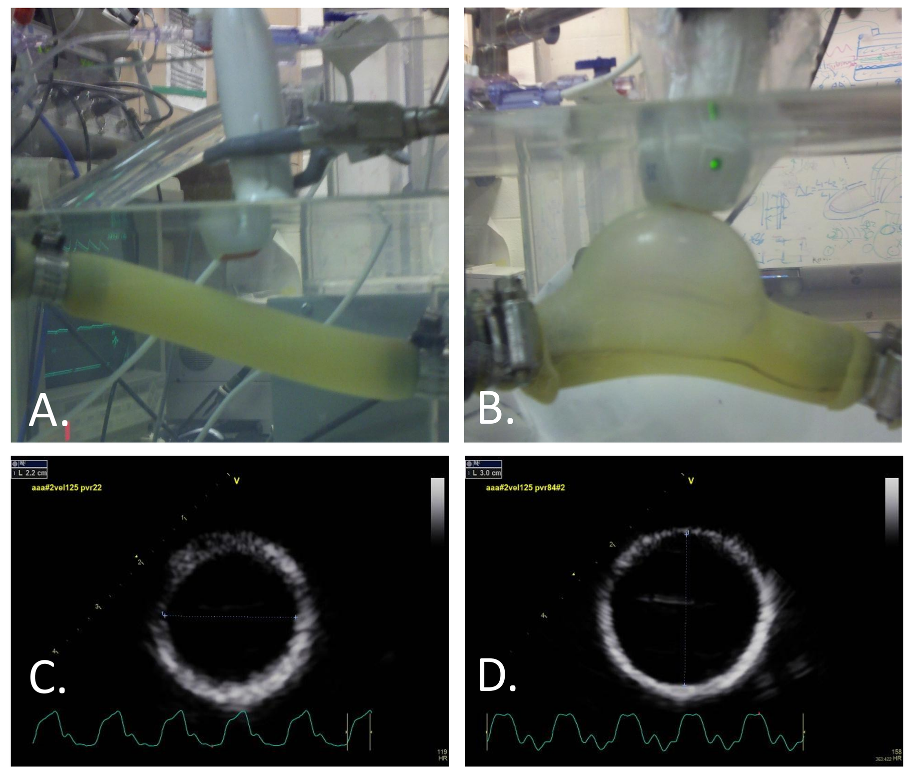


Figure #1: Overview of Ultrasound Strain Test Fixture
- Computer Controlled Pneumatic Compression Chamber
- Blood Mimicking Fluid
- Transonic Transit Time Flow Meter
- Hewlett Packard Multi-Parameter Pressure Monitor
- USB Network

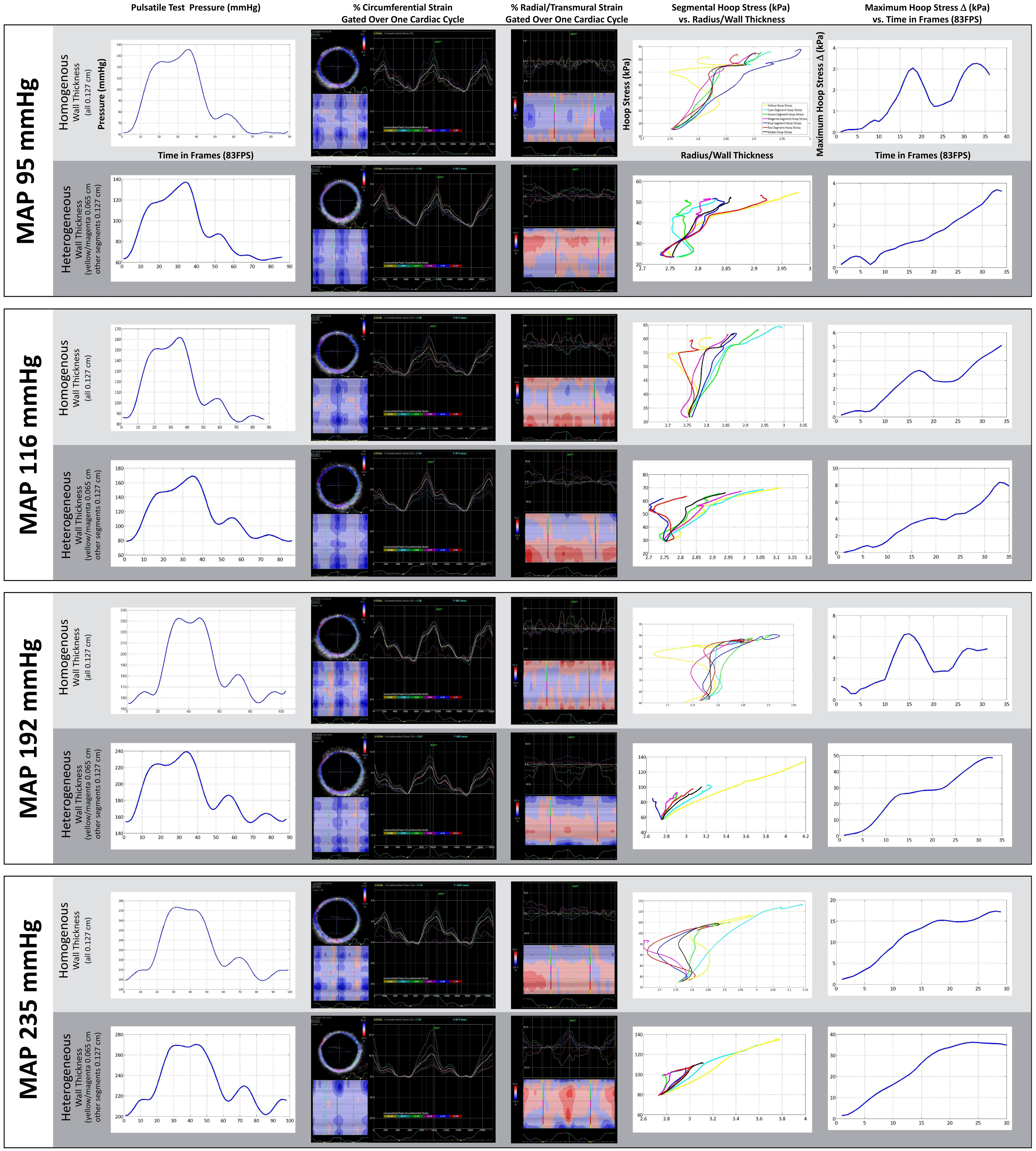
A homogenous wall thickness (0.127cm) and heterogeneous wall thickness (anterior wall 0.65cm/posterior wall 0.127cm) phantom where compared under various hemodynamic loading conditions (Table#1) using a pulsatile hemodynamic simulator (Figure #1). Hoop stress was calculated using real-time pressure and changes in vessel geometry as detected by a GE Vivid i ultrasound machine.



Figure#2: Vessel Phantoms Under Experimental Test Conditions

A. Homogenous Wall Thickness Phantom Under Pulsatile Test Load (MAP 235)
B. Heterogeneous Wall Thickness Phantom Under Pulsatile Test Load (MAP 235)
C. Heterogeneous Phantom Maximum Diastolic Diameter of 2.2 cm (MAP 95)
D. Heterogeneous Phantom Maximum Systolic Diameter of 3.0 cm (MAP 235)

Table #2: Results of Ultrasound Derived Wall Stress



Methods (Continued):

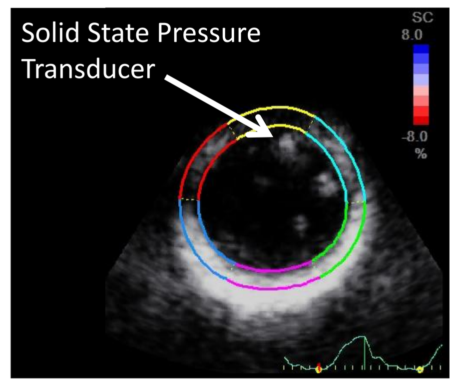


Figure #3: 2D ultrasound imaging indicating position of solid state pressure transducer during test. Pressure sensor placed 1cm out of field during test.

	Homogenous Model		Heterogeneous Model	
Test #	Pressure (mmHg)	Flow (LPM)	Pressure (mmHg)	Flow (LPM)
1	136/59 (93)	3.49	137/62 (95)	3.52
2	162/82 (117)	3.22	160/79 (115)	3.22
3	233/155 (191)	2.84	239/153 (193)	3.03
4	274/199 (235)	2.59	270/201 (234)	2.75

Table #1: Experimental hemodynamic test conditions during phantom testing.

Results:

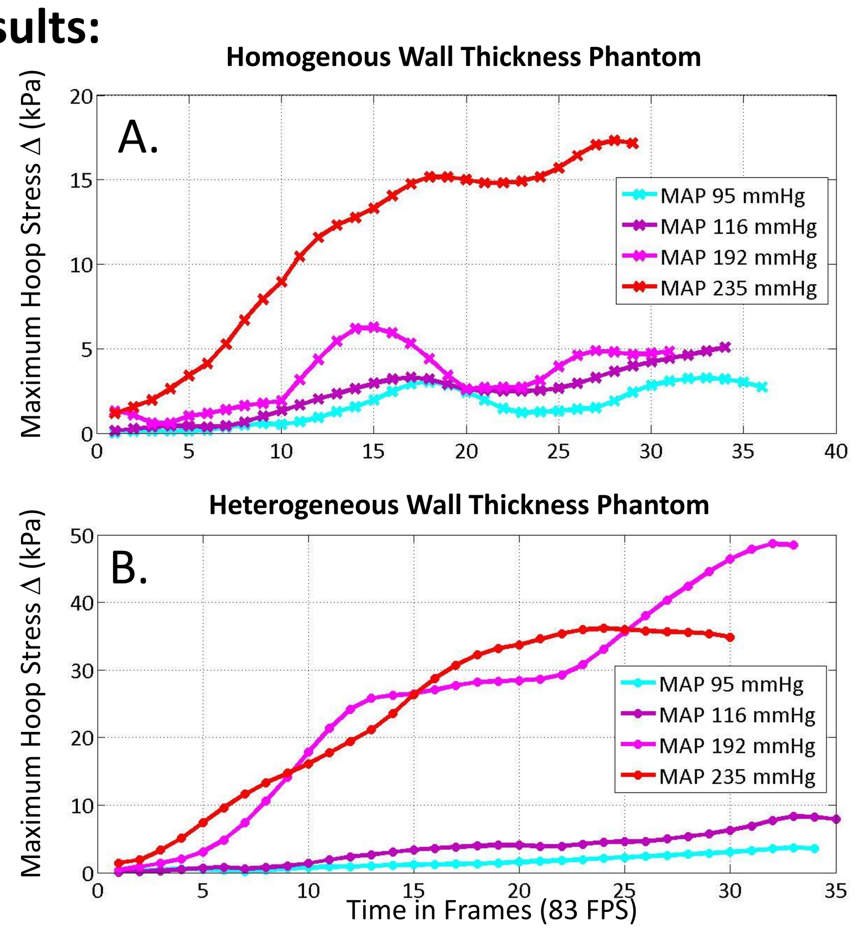


Figure #4: Comparison of maximum hoop stress variance in adjacent segmental areas of the homogenous (Figure #4.A) and heterogeneous (Figure #4.B) wall thickness phantoms during systolic loading. With significant loading the homogenous phantom begins to show disproportionate load sharing.

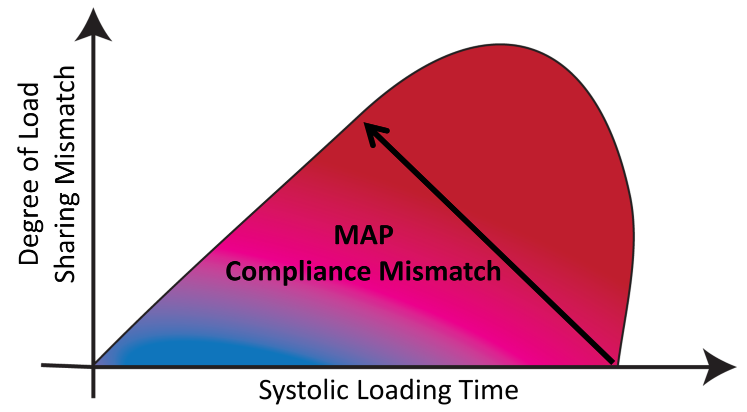


Figure #5: Conceptualization of increased load sharing disparity leading to aneurismal failure. As hemodynamic stress or the degree of compliance mismatch is increased linearly there is an exponential increase in mismatched aneurismal loading.

Conclusions:

Pressure gated transcutaneous 2D ultrasound of AAA phantom, provides:
- Quantification of dynamic hoop stress
- Likely location of aneurismal failure
- A predictive model of aneurismal behavior with hemodynamic loading

Limitations:
- Current experimental model has greater strength then human tissue

Future Work:
- Develop a phantom with tissue like mechanical properties
- Investigate pressure gated strain in AAA patient cohort
- Study potential 3D pressure gate strain analysis

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