Irregular Blood Flow Patterns in the Development of Pulmonary Hypertension

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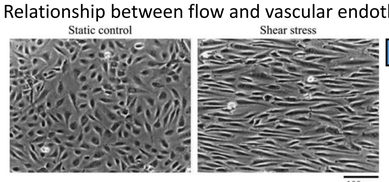
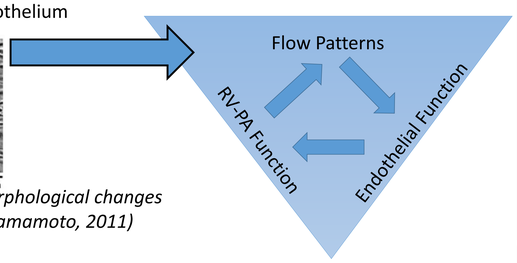
Introduction

- Pulmonary Arterial Hypertension (PAH)
  - ↑ Pulmonary Vascular Resistance (PVR)
  - ↑ Pulmonary Vascular Stiffness (PVS)
  - ↑ Mean Pulmonary Arterial Pressure (mPAP)

→ Ultimately Leading to Right Ventricular (RV) Failure

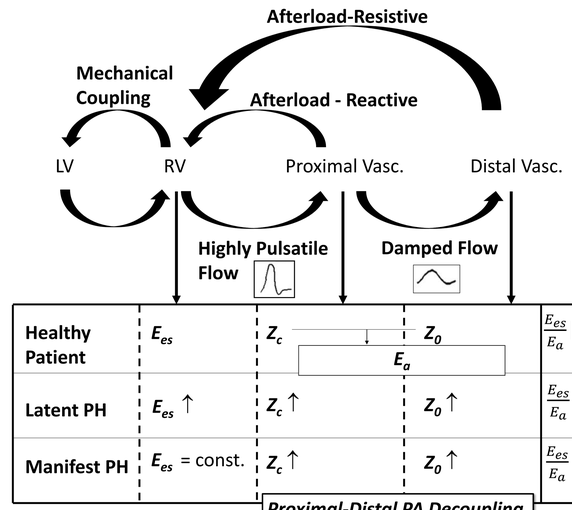
- Relationship between flow and vascular endothelium





Evidence of Endothelial realignment and morphological changes in response to luminal flow (J. Ando and K. Yamamoto, 2011)

- Biomechanics of PAH and Study Motivation



Legend

- E_{es} *= End-systolic Elastance (Contractility)*
- *Zc = Characteristic Impedance (reactive afterload)*
- $Z_0 \approx$ *PVR (Resistive afterload)*
- E_a *= Arterial Elastance (Comprehensive Afterload)*

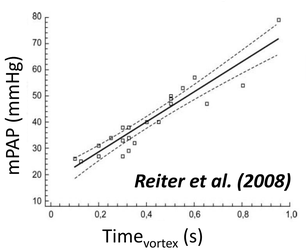
				RV-PA Decoupling
Healthy Patient	E_{es}	Z_c	Z_0	$\frac{E_{es}}{E_a}\|_{baseline}$
Latent PH	E_{es} ↑	Z_c ↑	Z_0 ↑	$\frac{E_{es}}{E_a}\|_{latent} = \frac{E_{es}}{E_a}\|_{baseline}$
Manifest PH	E_{es} = const.	Z_c ↑	Z_0 ↑	$\frac{E_{es}}{E_a}\|_{manifset} < \frac{E_{es}}{E_a}\|_{baseline}$

Proximal-Distal PA Decoupling

Index of Wave Reflection (Γ) = (PVR – Characteristic Impedance)/(PVR + Characteristics Impedance)

Question: What is happening in local flow dynamics?

- ***Answer: Vortex existence time increased concurrently with mPAP***



- ***Interpretation***
  - ***RV-Pulmonary Artery (PA) decoupling is reflected in the PA flow patterns***
- ***Significance (prognostic)***
  - ***Flow patterns are highly sensitive to fluid-structure interactions***
    - ***Lasting evidence of subtle disruptions***
- ***Significance (research)***

Flow Patterns ⇄ ***Endothelial Function***

- Study Objectives
  - *Identify flow variables that describe velocity patterns in the PA*
  - *Associate PA flow patterns with RV-PA functional prognostic markers*
- Hypothesis
  - *Vorticity, Helicity and Wall Shear Stress change in PAH*
  - *Changes in flow pattern markers are associated with changes in functional markers*

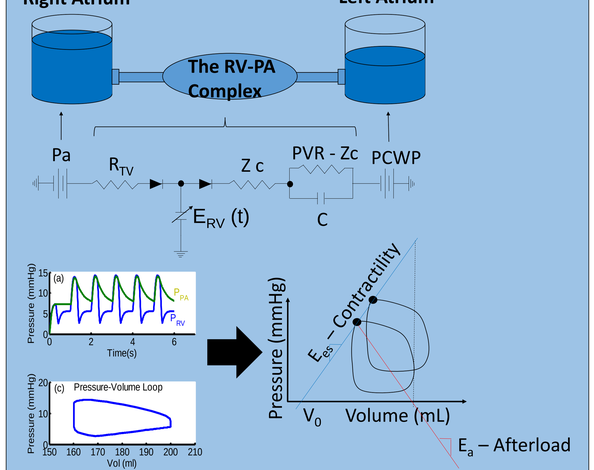
Methods

- Demographics
  - Dataset: 22 Patients w/ PAH symptoms:

→ Each Patient in DATASET

- Flow Kinematics
  - 4D MRI (5CTL vs. 17PH)
    - Data analyzed at peak systole
      - Magnitude of the Vorticity Vector ($|\vec{\omega}|$)
      - Helicity Index = $\frac{1}{N_k}\sum_{k=\,Sum\ over\ entire\ mesh}\left|\frac{\vec{\omega}\cdot\vec{v}}{|\omega||v|}\right|$
      - Wall Shear Stress: $\tau = \mu(Ht)\frac{du}{dy}$

- RV-PA Coupling
  - Traditional Hemodynamics (3CTL vs. 17 PH)
    - mPAP
    - PVR
    - Work = CO*mPAP
    - PP
  - RV-PA Coupling Assessment



$$VVC = \frac{E_{es}\ (Contractility)}{E_a(Afterload)}$$

- Proximal Distal Pulmonary Arterial Coupling
  - Impedance mismatch between the proximal and distal vasculature: Index of Wave Reflection, Γ

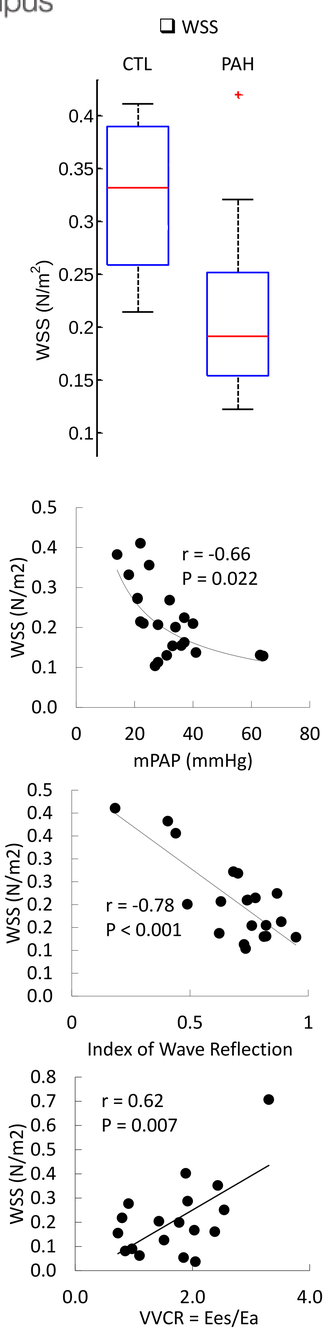
$$PAP_{mean} = \frac{[(1 + D \cdot PCWP)^5 + 5D \cdot PVR' \cdot CO]^{1/5} - 1}{D}$$

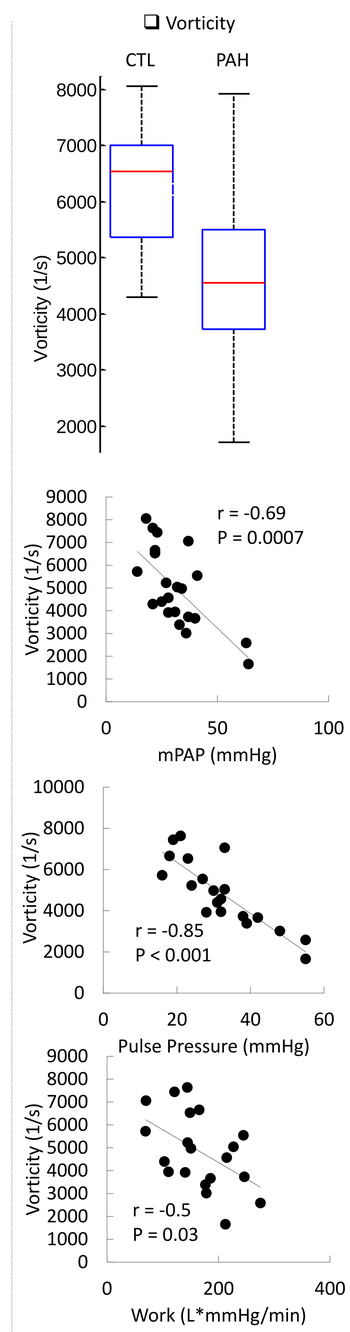
$$Z_c = \sqrt{\frac{\rho E h}{2\pi^2 R^5}} \longrightarrow \sqrt{\frac{1}{\rho D}} = \sqrt{\frac{Eh}{2\rho R}} \longrightarrow Z_c = \frac{\rho}{\pi R^2}\sqrt{\frac{1}{\rho D}}$$

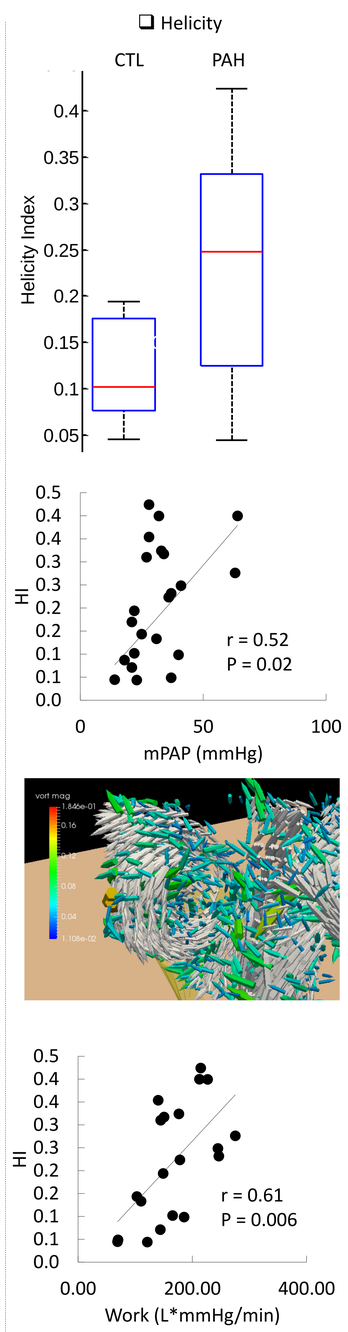
$$\Gamma = \frac{PVR - Z_c}{PVR + Z_c}$$

Results

- Flow markers are changed in PH







Discussion

- Clinical Translation:
  - Flow patterns, available from 4D MRI, are indicative of vascular and ventricular function
  - Need larger CTL and PH samples
- Research Translation
  - Flow patterns are associated with RV function, distal constriction (resistive afterload), and proximal remodeling (reactive afterload)
  - Helical flow patterns could have implications on bulk transport efficiency
  - WSS ↔ Endothelial Function ↔ Vascular Function ↔ RV-PA Function

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