Irregular Blood Flow Patterns in the Development of Pulmonary Hypertension


Introduction

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

Relationship between flow and vascular endothelium

Flow Patterns

Demographics

- Dataset: 22 Patients w/ PH symptoms
- Each Patient in DATASET

Methods

Flow Kinematics

- 4D MRI (3CTL vs. 17PH)
- Data analyzed at peak systole
  - Magnitude of the Vorticity Vector (|\(\omega\)|)
  - Helicity Index \(\iota = \frac{\omega \cdot \nabla \times v}{\omega \cdot \nabla \times \omega}\)
  - Wall Shear Stress: \(\tau = \mu |\nabla \times v|\)

RV-PA Coupling

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

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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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):

- Vorticity, Helicity and Wall Shear Stress change in PAH
- Changes in flow pattern markers are associated with changes in functional markers

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

Data analyzed at peak systole

Magnitude of the Vorticity Vector (|\(\omega\)|)

Helicity Index \(\iota = \frac{\omega \cdot \nabla \times v}{\omega \cdot \nabla \times \omega}\)

Wall Shear Stress: \(\tau = \mu |\nabla \times v|\)

Flow patterns are associated with RV function, distal constriction (resistive afterload), and proximal vasculature: Index of Wave Reflection, \(\Gamma\)

Proximal Distal Pulmonary Arterial Coupling

- Impedance mismatch between the proximal and distal vasculature: Index of Wave Reflection, \(\Gamma\)

\[ PAP_{max} = \frac{1}{1 + B \cdot PCWP} + S0 \cdot PVR' - CO' \frac{1}{1 + B} - 1 \]

\[ Z_L = \frac{\rho h \sqrt{2\pi l}}{\sqrt{\pi l^2}} \cdot \frac{1}{\frac{1}{PD}} = \frac{E_h}{\pi l^2} \cdot Z_L = \frac{P}{\pi l^2} \cdot \frac{1}{\frac{1}{PD}} \]

\[ \tau = \frac{PVR - Z_L}{PVR + Z_L} \]

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

- Ees = End-systolic Elasticity (Compliance)
- Zc = Characteristic impedance (reactive afterload)
- ZL = PVR (Resistive afterload)
- Ea = Arterial Elasticity (Comprehensive Afterload)

Mechanical Coupling

Afterload - Reactive

LV - RV - Proximal Vasc. - Distal Vasc.

Afterload - Reactive

Highly Pulsatile

Damped Flow

RV-PA Decoupling

Proximal-Distal PA Decoupling

Index of Wave Reflection (1 + PVR = Characteristic Impedance/\(PVR + \) Characteristic Impedance)

Research Translation:

- Flow patterns are associated with RV function, distal constriction (resistive afterload), and proximal remodeling (reactive afterload)
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WSS \(<\) Endothelial Function \(<\) Vascular Function \(<\) RV-PA Function

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