ARTERY 2016, Copenhagen

Wave Intensity Analysis Provides Novel Insights into Pulmonary Hypertension

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Background

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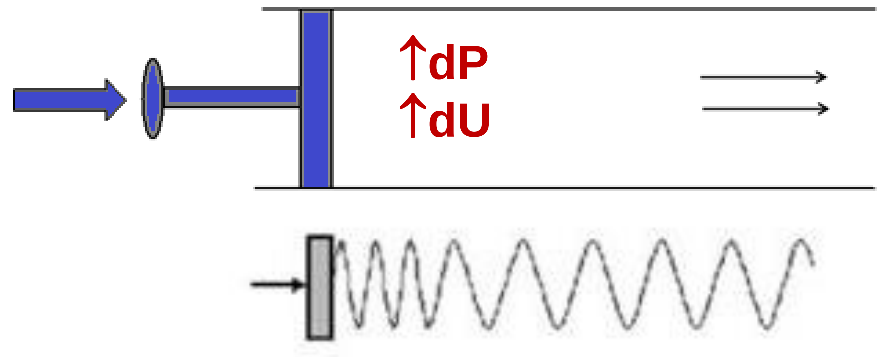
Arterial waves

Proximal artery

Forward compression wave (FCW)



P: pressure
U: velocity

Su *et al.*, Acta Physiol, 2016

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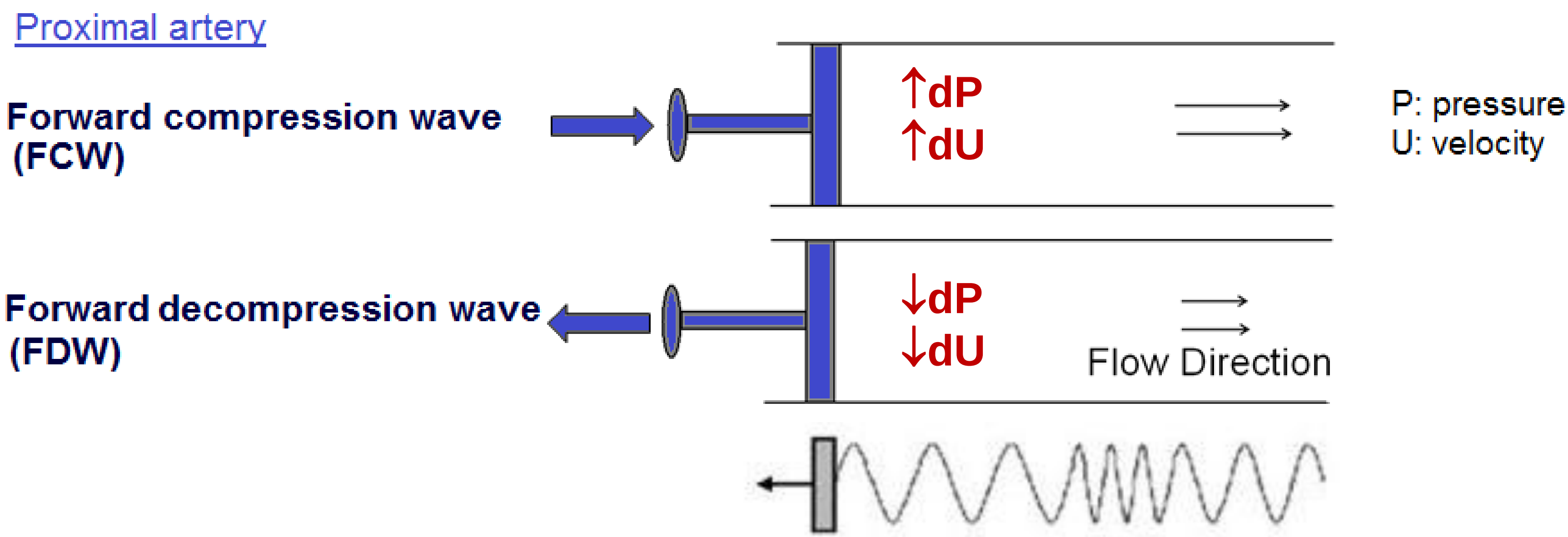
Arterial waves



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Arterial waves

Proximal artery

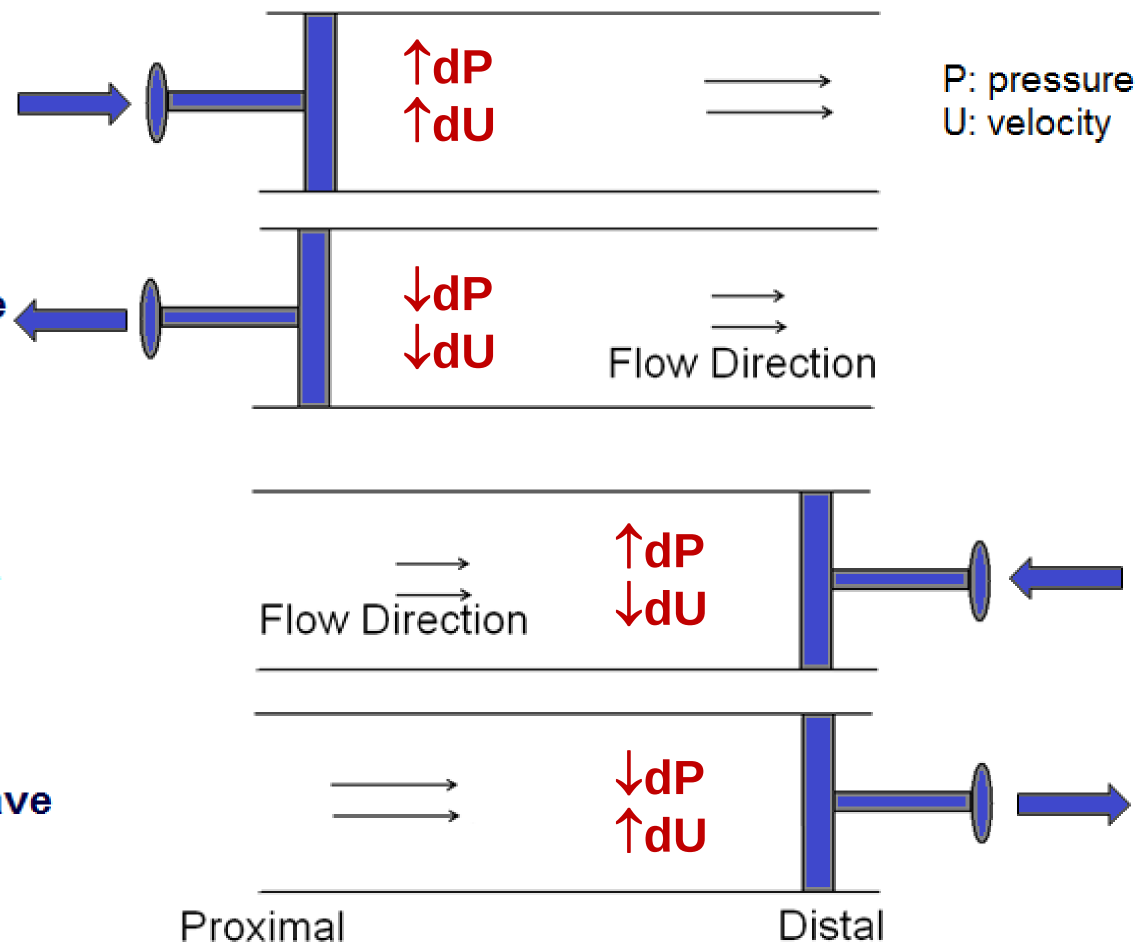
Forward compression wave (FCW)

Forward decompression wave (FDW)

Distal artery

Backward compression wave (BCW)

Backward decompression wave (BDW)



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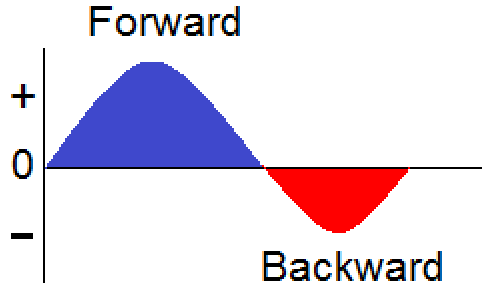
Wave intensity analysis (WIA)

- **Analysis of the incremental changes in pressure (P) and flow velocity (U) in a circulation**

- **Wave intensity: energy carried by a wave**

$$dI = dP \times dU \quad (\text{Unit } W/m^2 = J/sm^2)$$



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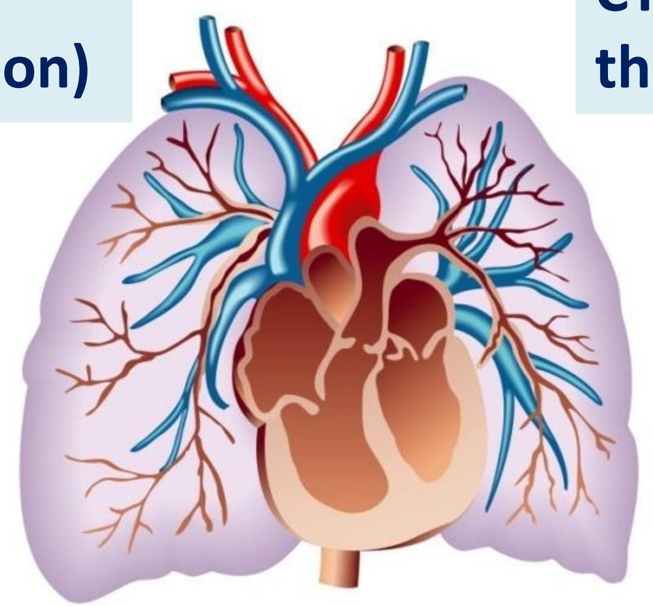
Pulmonary hypertension (PH)

Mean pulmonary arterial pressure (PAPm) ≥ 25 mmHg
→ right heart failure

PAH (Pulmonary arterial hypertension)

CTEPH (Chronic thromboembolic PH)



PH due to left heart disease

PH with unclear or multifactorial causes

PH due to lung disease

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WIA in pulmonary artery

EUROPEAN RESPIRATORY *journal*

OFFICIAL SCIENTIFIC JOURNAL OF THE ERS

Assessment of ventriculo-arterial interaction in pulmonary arterial hypertension using wave intensity analysis

Edmund M.T. Lau[1,2,3], David Abelson[2], Nathan Dwyer[4], Young Yu[1,2], Martin K. Ng[1,2] and David S. Celermajer[1,2]

AMERICAN JOURNAL of PHYSIOLOGY

American Physiological Society

Heart and Circulatory Physiology®

Noninvasive pulmonary artery wave intensity analysis in pulmonary hypertension

Michael A. Quail,[1] Daniel S. Knight,[1,2] Jennifer A. Steeden,[1] Liesbeth Taelman,[3] Shahin Moledina,[1] Andrew M. Taylor,[1] Patrick Segers,[3] J. Gerry Coghlan,[2] and Vivek Muthurangu[1]

- **WIA in the pulmonary artery in man is feasible!**
- **Clinical implications?**

Lau *et al*, Eur Respir J, 2014
Quail *et al*, Am J Physiol, 2015

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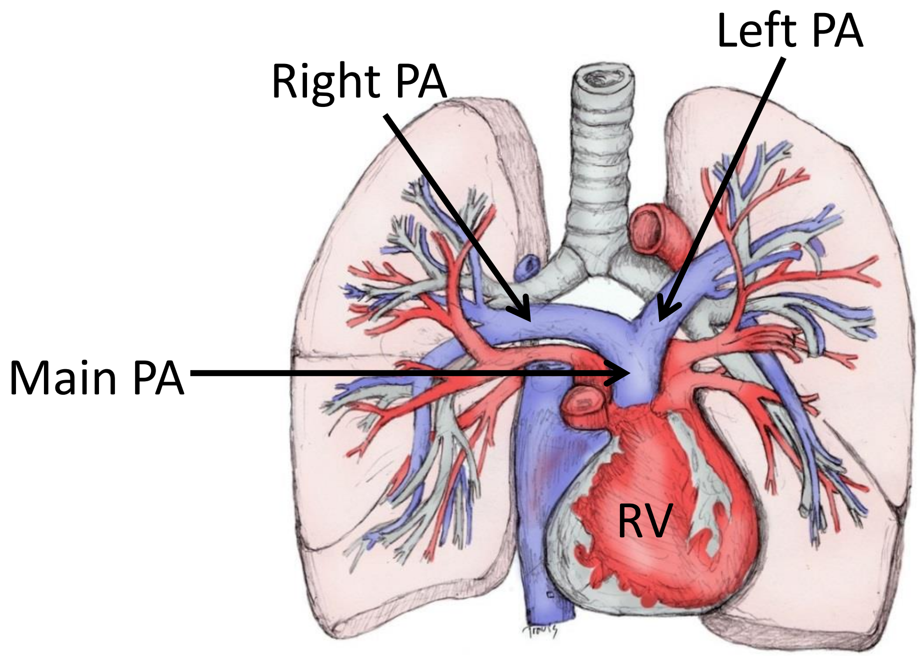
Objective

- **Assess arterial wave characteristics in the pulmonary artery**
- **Explore the clinical usefulness of WIA in pulmonary hypertension**



Study design

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Inclusion criteria

- **Patients referred to the cardiac catheterisation laboratory for clinical reasons**
- **Control subjects: no significant heart or lung disease**
- **PH patients: patients with confirmed or suspected PAH or CTEPH**

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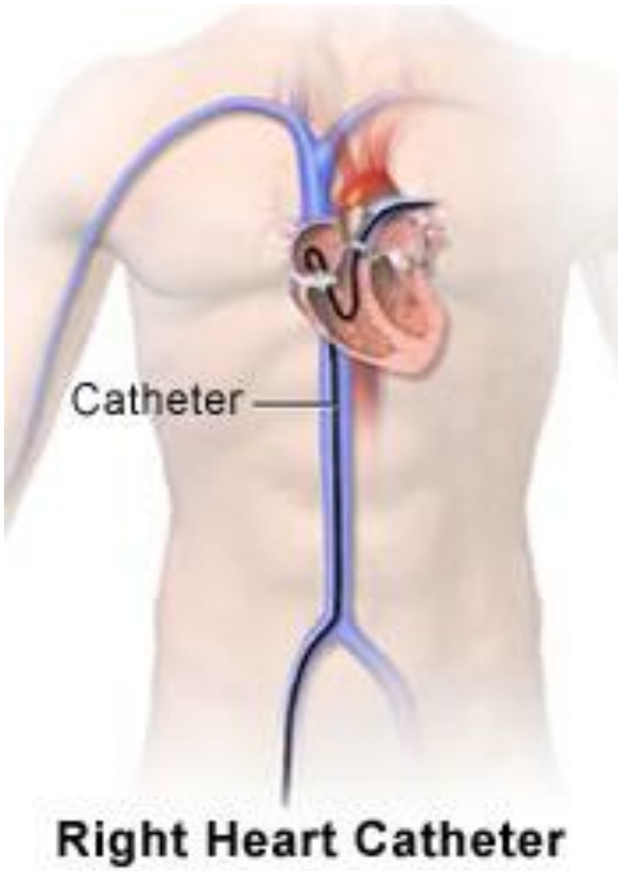
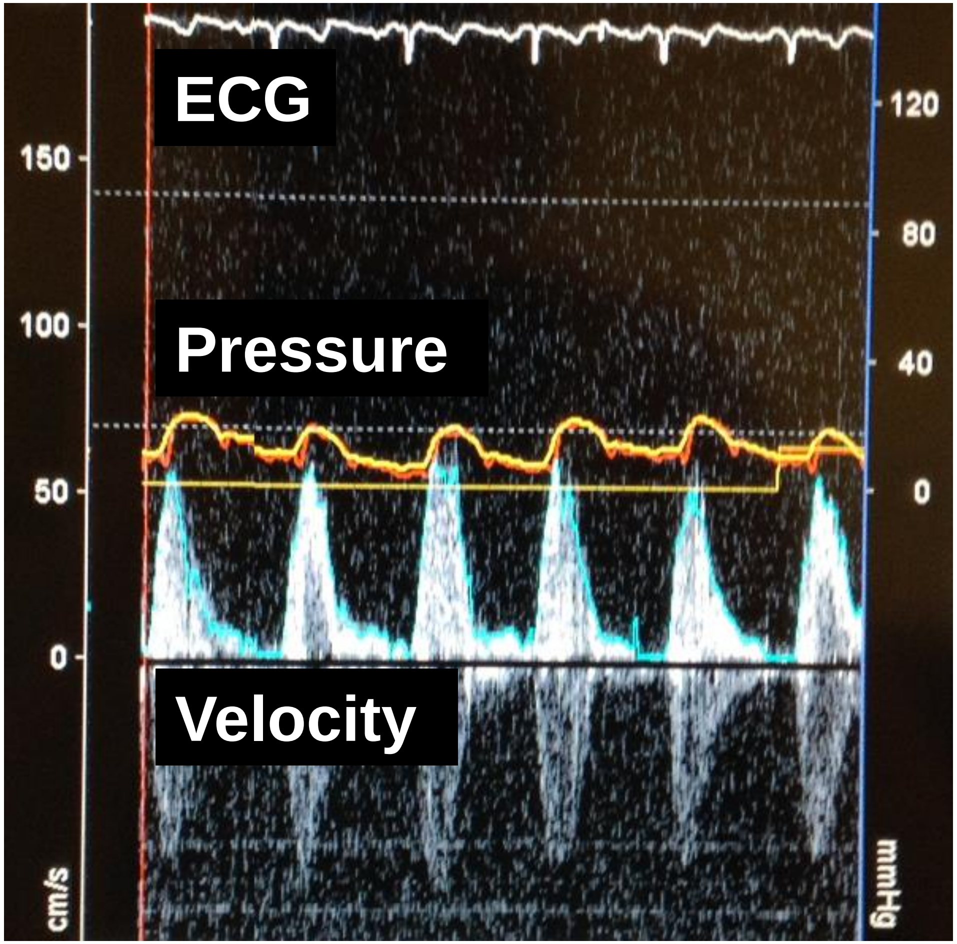
Right heart catheterisation

Right heart catheterisation with simultaneous pressure and velocity measurements.





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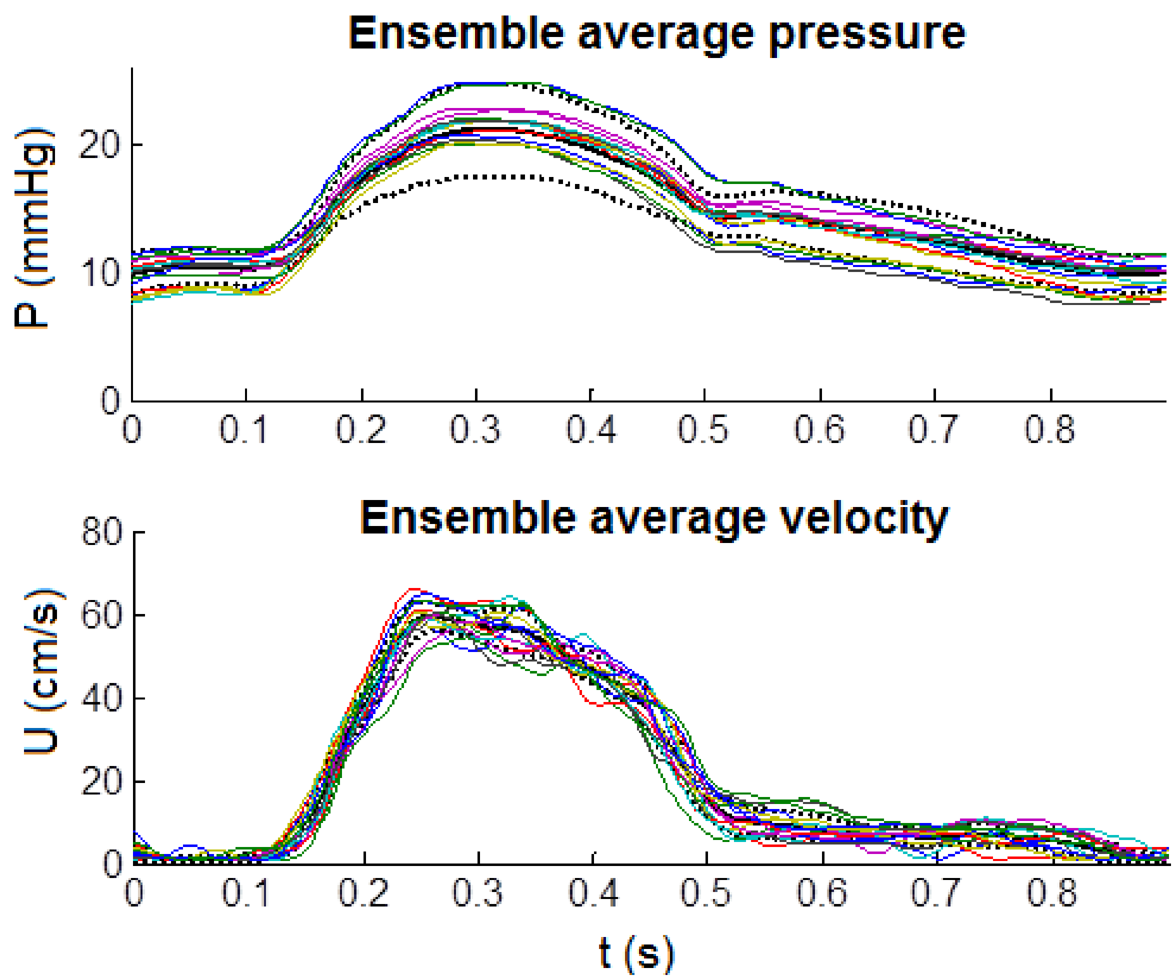
Data processing

- **Data ensemble averaged using the R-wave of ECG**



Data processing

- Data ensemble averaged using the R-wave of ECG
- **Calculation of wave speed (sum of squares method)**

$$c = \frac{1}{\rho} \cdot \sqrt{\frac{\sum dP^2}{\sum dU^2}}$$

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Data processing

- Data ensemble averaged using the R-wave of ECG
- Calculation of wave speed (sum of squares method)
- **Wave intensity (WI) normalized to number of samples in the cardiac cycle**

$$WI = dP\frac{CCD}{dt} \cdot dU\frac{CCD}{dt}$$

CCD: cardiac cycle duration

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Data processing

- Data ensemble averaged using the R-wave of ECG
- Calculation of wave speed (sum of squares method)
- Wave intensity (WI) normalized to number of samples in the cardiac cycle
- **Separation of forward and backward waves**

$$Forward: \quad WI_{+} = \left(\frac{dP \cdot CCD}{dt} + \rho \cdot c \frac{dU \cdot CCD}{dt} \right) \Big/ 4\rho c$$

$$Backward: WI_{-} = -\left(\frac{dP \cdot CCD}{dt} - \rho \cdot c \frac{dU \cdot CCD}{dt} \right) \Big/ 4\rho c$$

Results

Study subjects

Recruited
N = 36

Excluded
N = 5

Control
N = 10
PAPm: 17 mmHg

PAH
N = 11
PAPm: 47 mmHg

CTEPH
N = 10
PAPm: 48 mmHg

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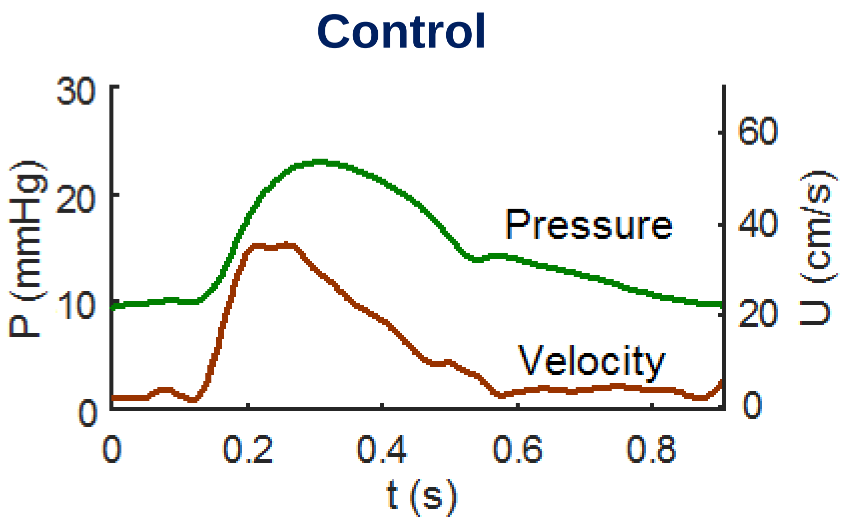
WIA pattern



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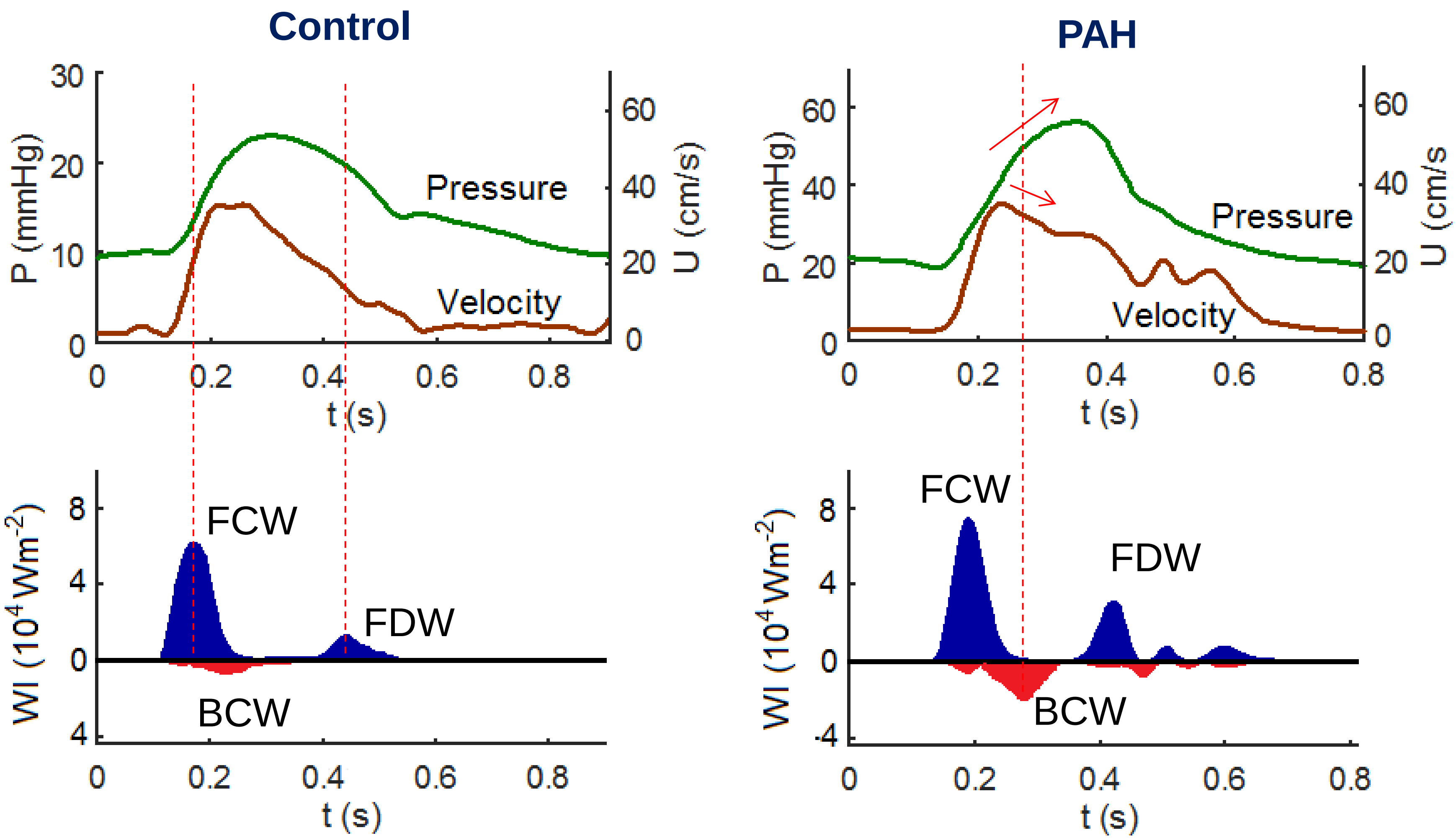
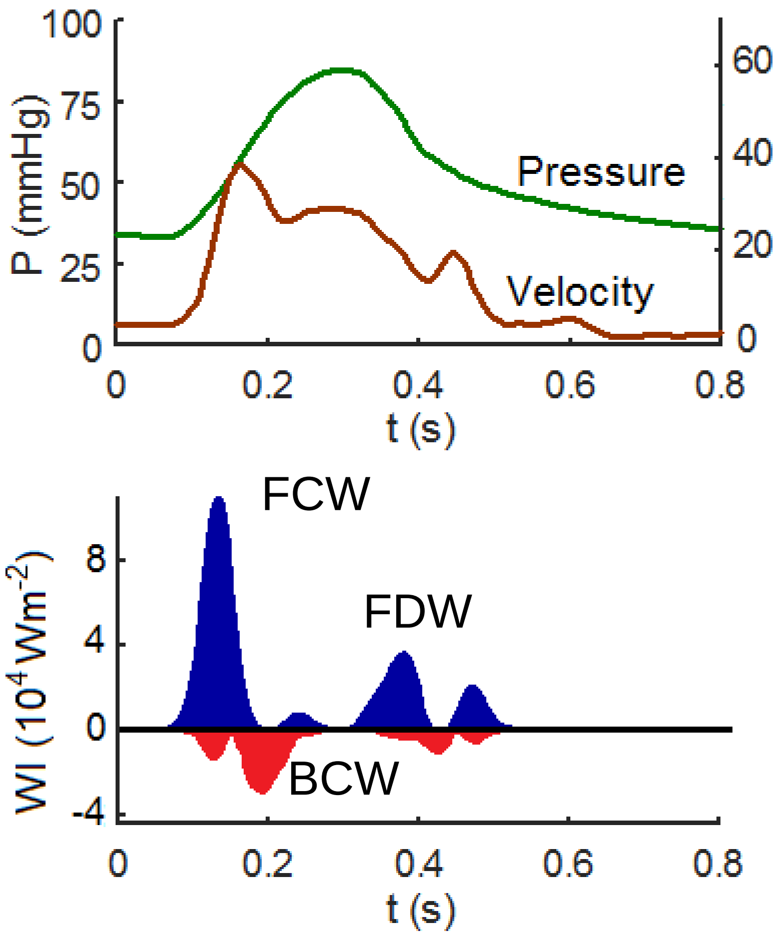
WIA pattern

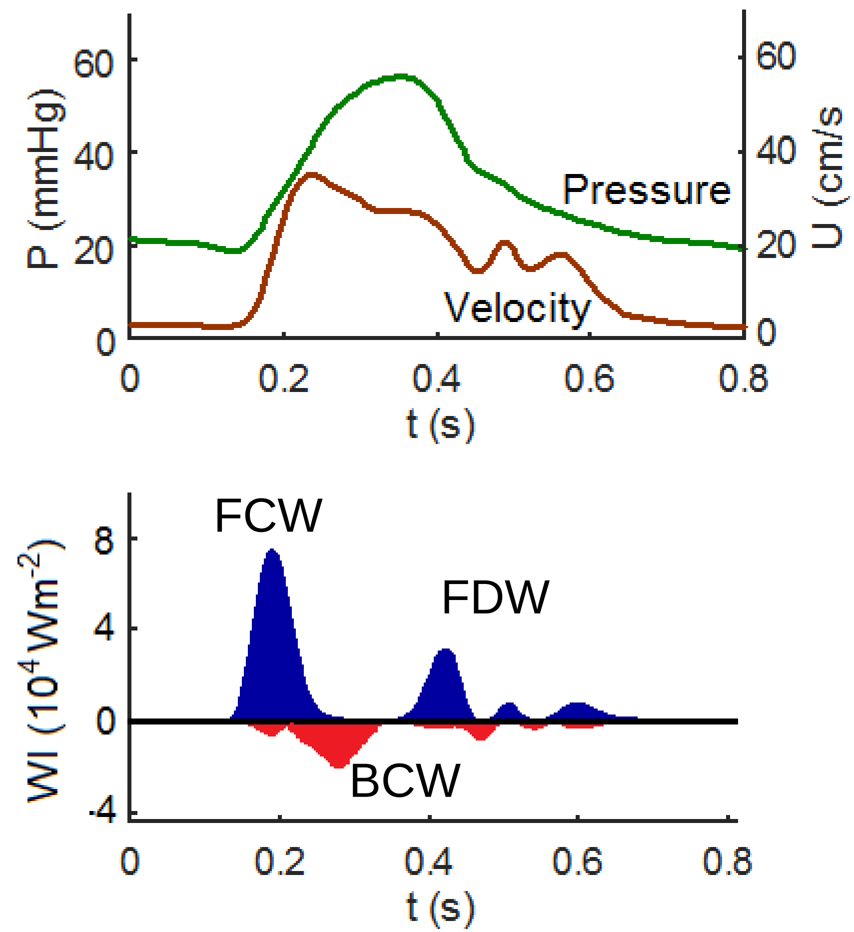


WIA pattern

CTEPH



PAH



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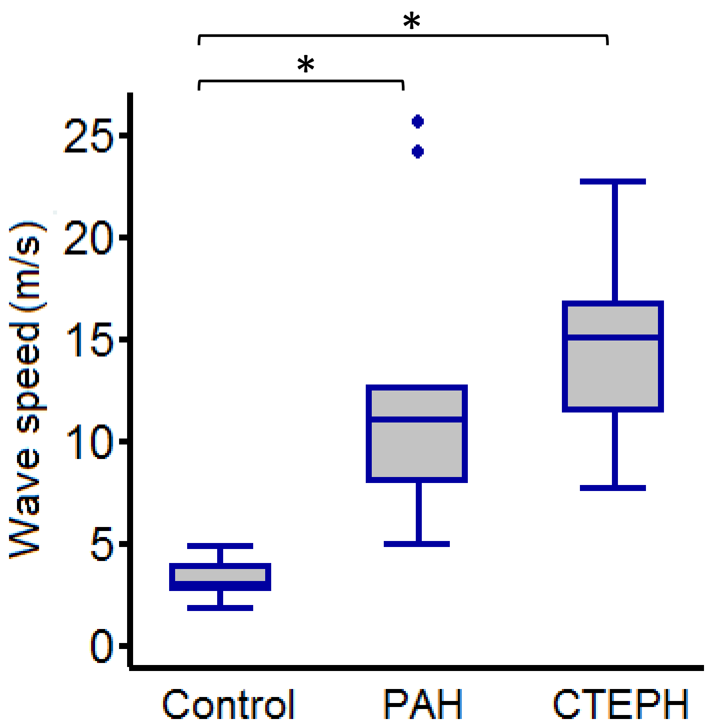
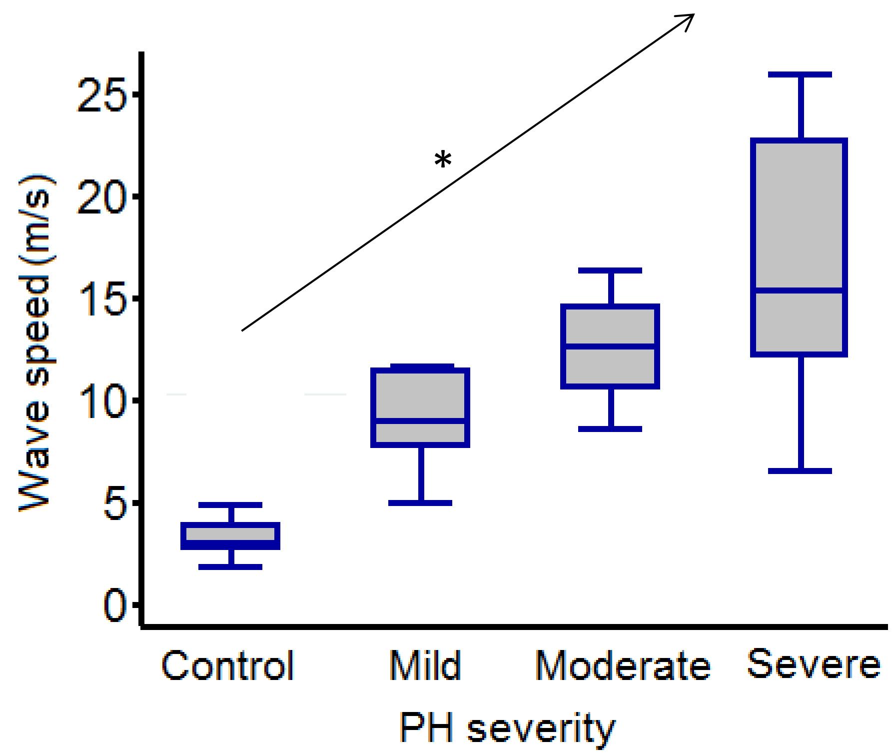
Wave speed

PH patients = PAH + CTEPH

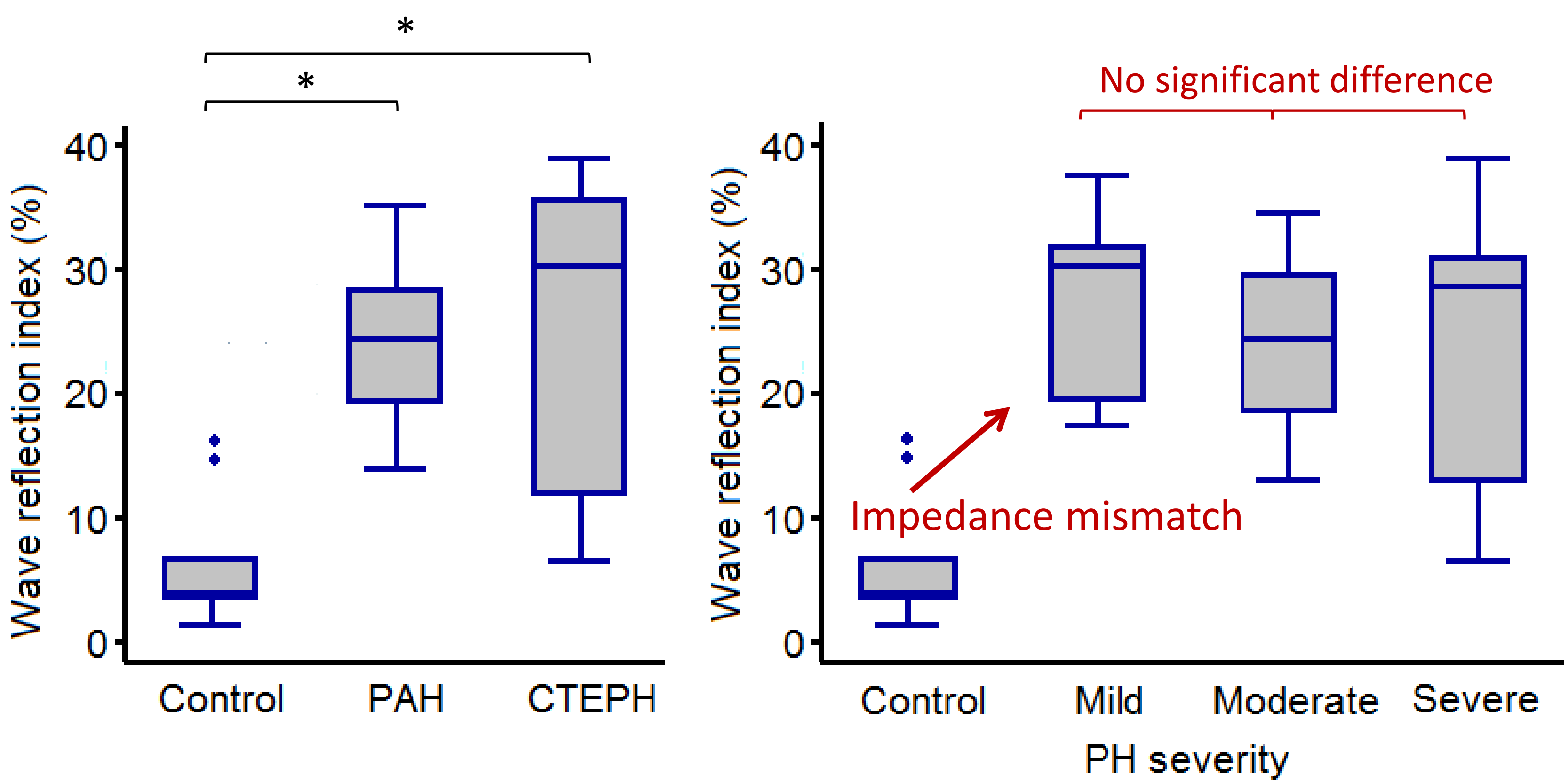




Wave reflection

Wave reflection index (WRI) = BCW/FCW

Wave reflection



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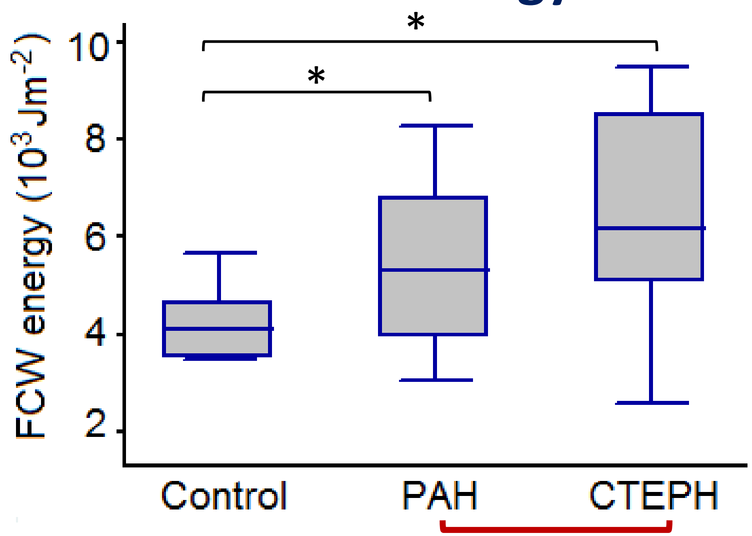
The right ventricle

FCW energy



No significant difference

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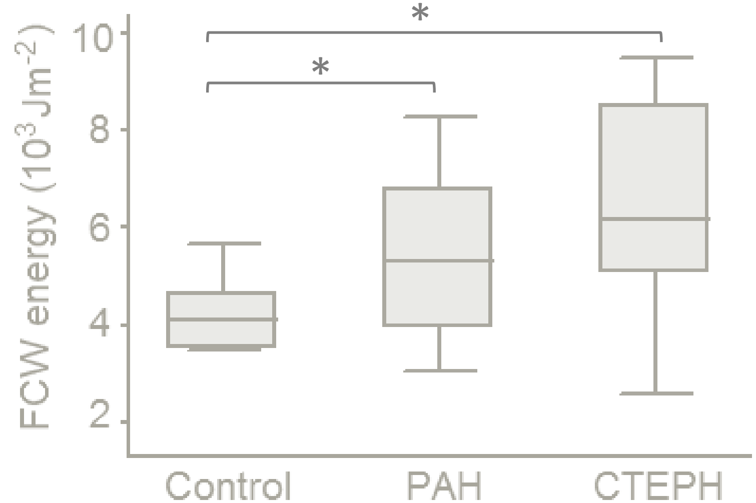
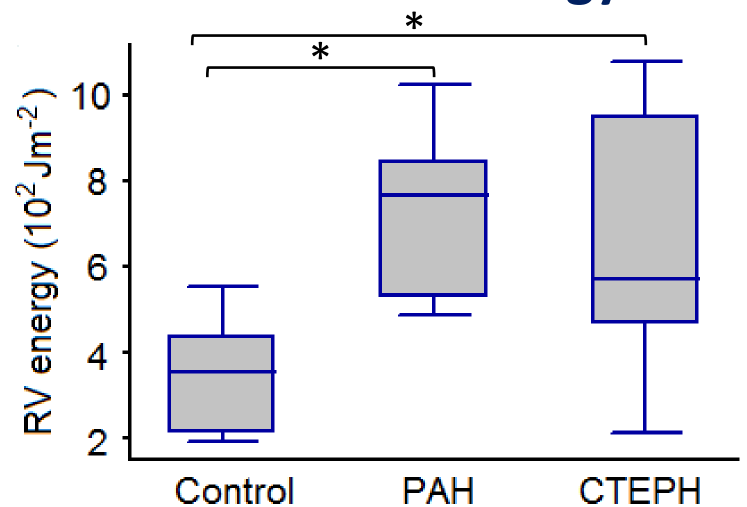
The right ventricle

FCW energy



RV stroke energy



No significant difference

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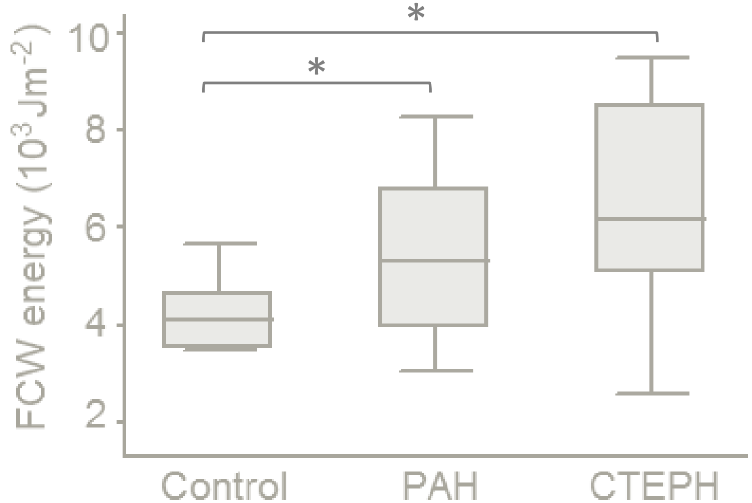
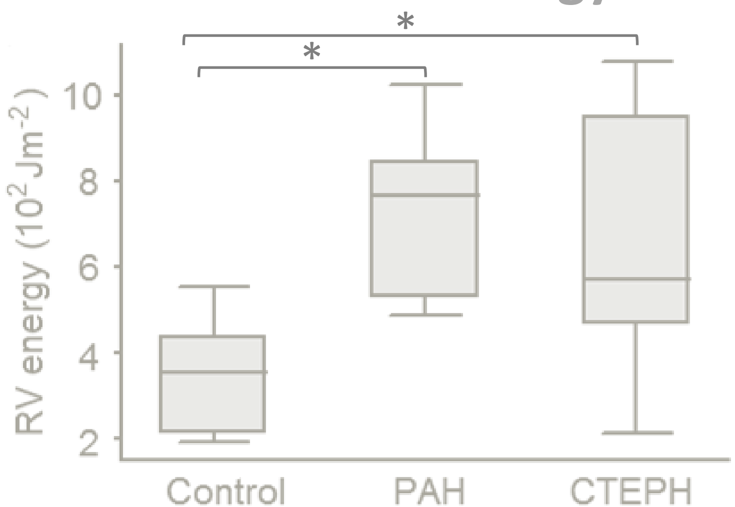
The right ventricle

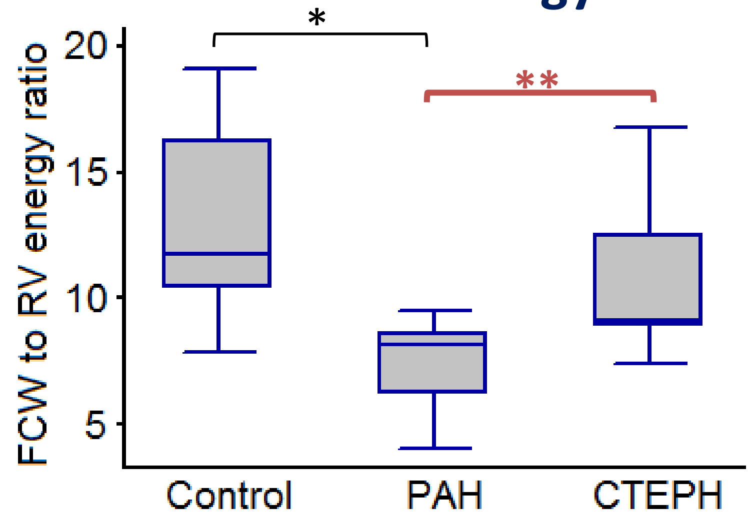
FCW energy



RV stroke energy



FCW to RV energy ratio



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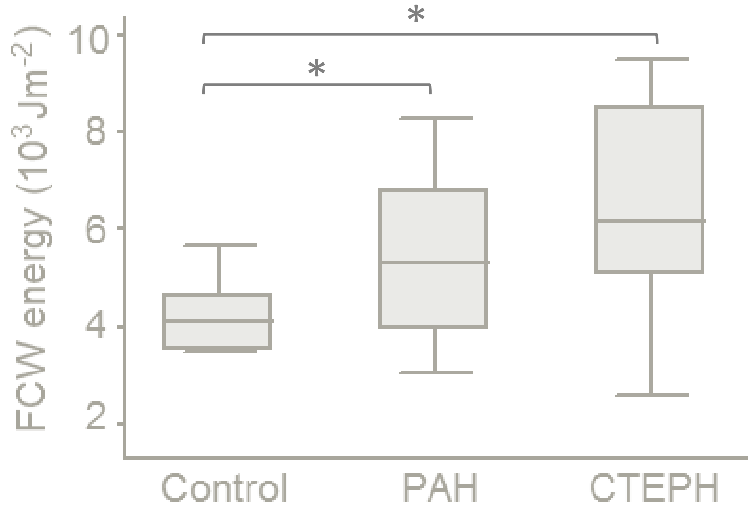
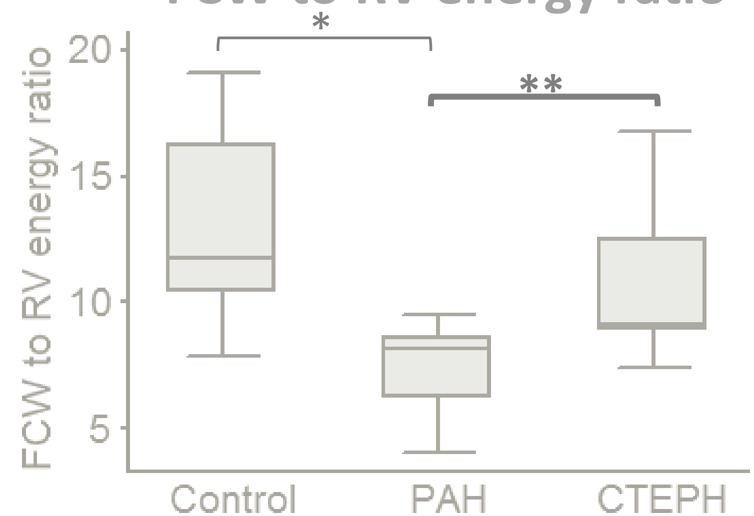
The right ventricle

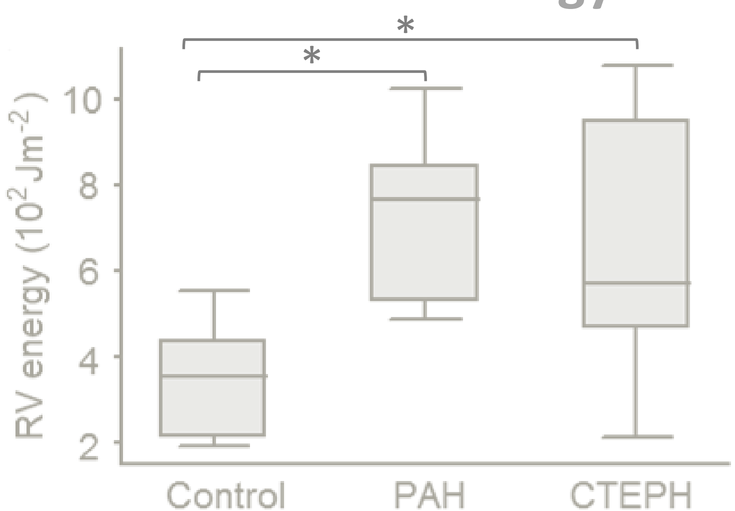
FCW energy



FCW to RV energy ratio

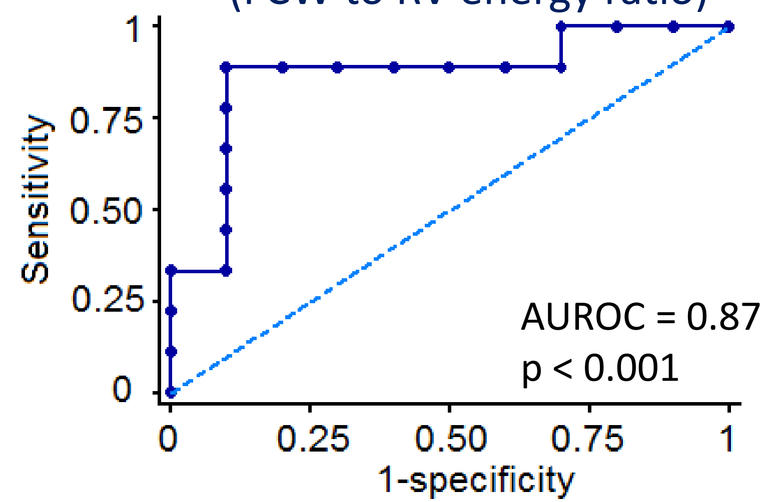


RV stroke energy



Differentiating CTEPH from PAH

(FCW to RV energy ratio)



Discussion and conclusion

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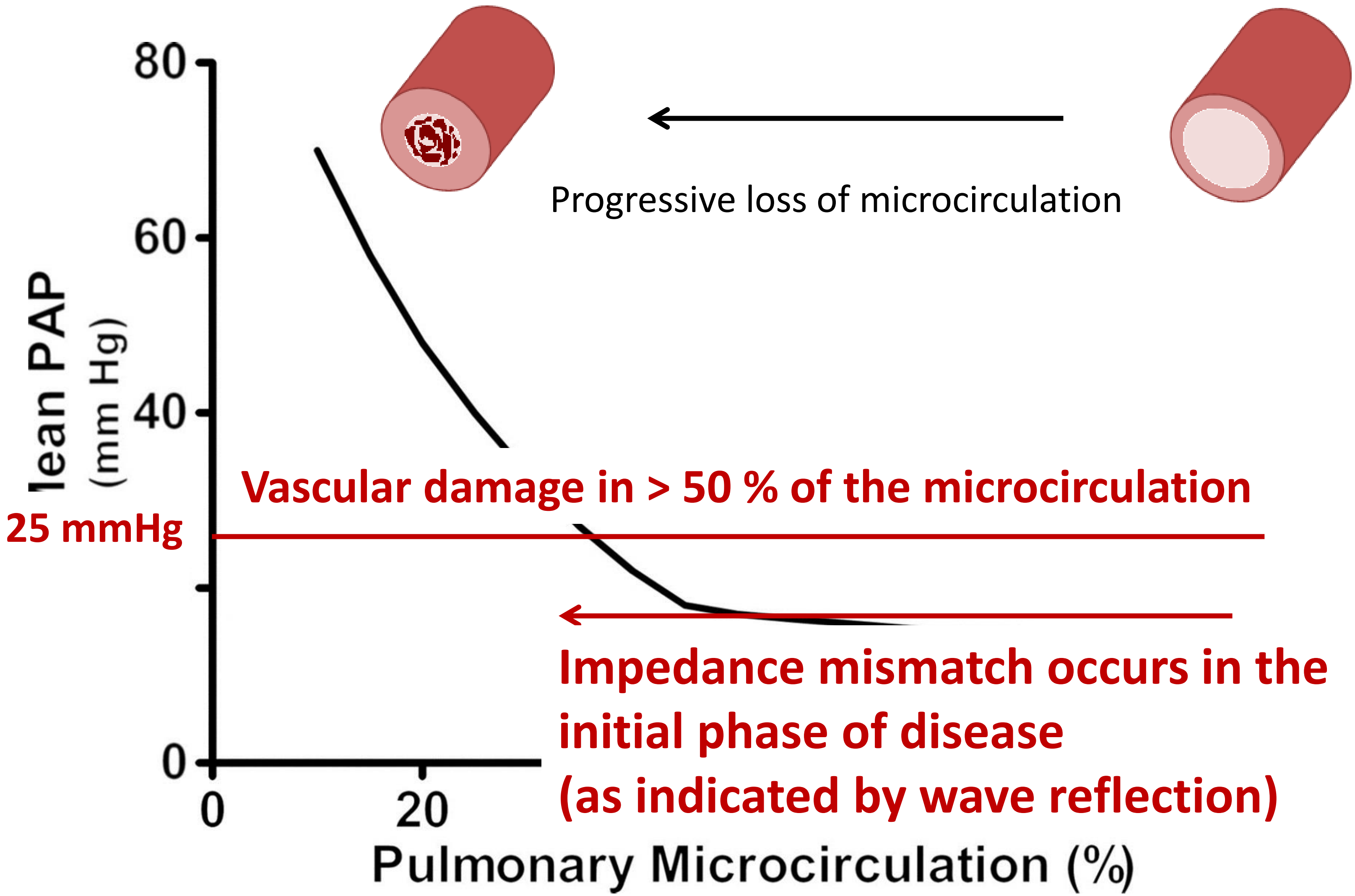
Early detection of disease



Lau *et al.*, Eur Heart J, 2011

PAH versus CTEPH

- PAH: pharmacological treatment
- CTEPH: pulmonary endarterectomy

- <u>FCW to RV energy ratio</u> greater in CTEPH than PAH

  ⇒ differences in RV function

  CTEPH: rapid adaptation

  PAH: gradual adaptation

- May serve as an additional measurement

Conclusion

- Wave speed increases in PH ⇒ greater arterial stiffness.

- Wave reflection is minimal in individuals without pulmonary vascular disease.
- Large wave reflection in pulmonary hypertension and it is unrelated to severity.
- Increased wave reflection may be an early indicator of pulmonary vascular disease.

- FCW to RV energy ratio can differentiate between PAH and CTEPH.

Thank you!

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Acknowledgements

Aarhus group:

[1]Prof Ulf Simonsen,[2]Dr Jens Erik Nielsen-Kudsk, [3]Dr Ole Hilberg, [2]Dr Soren Mellemkjaer,

1. Department of Biomedicine, Aarhus University
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3. Department of Respiratory Medicine, Aarhus University Hospital

London group:

[1,2]Prof Alun Hughes, [3]Prof Kim Parker, [1]Dr Charlotte Manisty, [2]Dr Luke Howard

1. Department of Cardiovascular Sciences, University College London
2. National Heart and Lung Institute, Imperial College London
3. Department of Bioengineering, Imperial College London

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Kornings Fond
Bønnelyckes Fond
Eva og Henry Frænkels Mindefond

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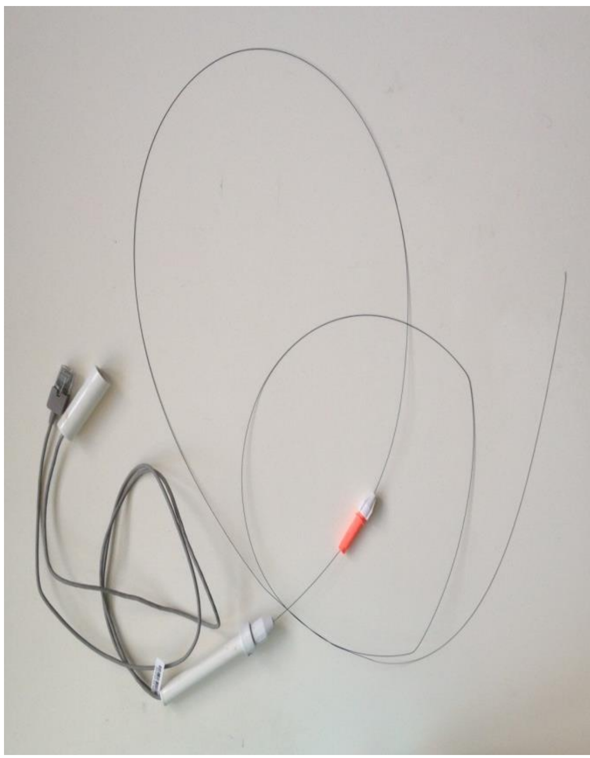
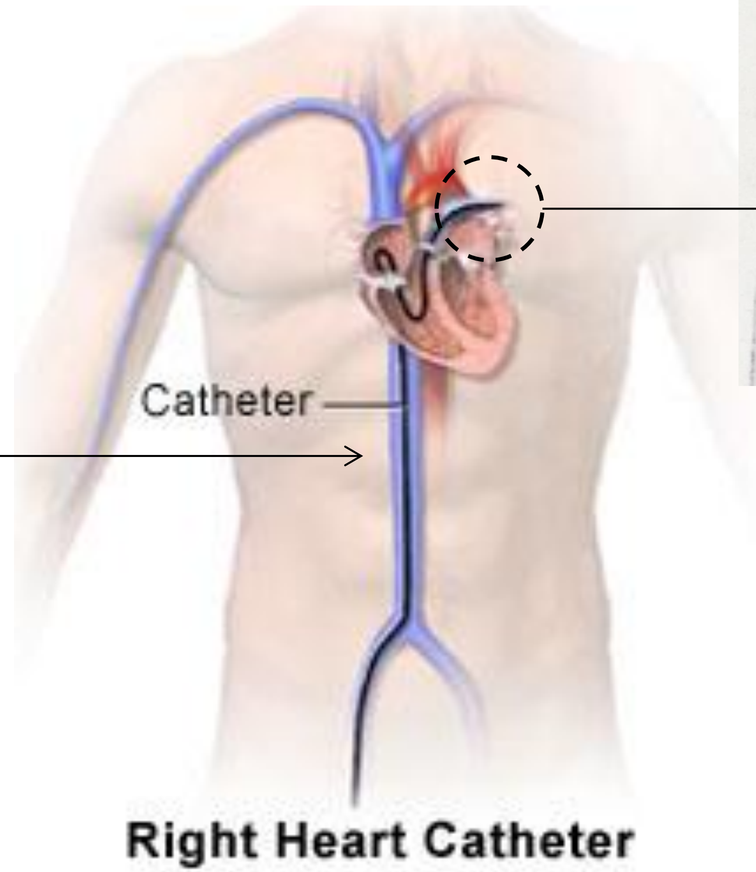
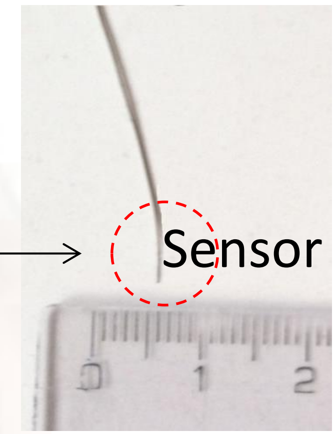
Right heart catheterisation

Combowires







Calculations – wave intensity

"Original" wave intensity (Wm^{-2})

$$dI = dP \cdot dU$$

"Time-normalized" Wave intensity ($Wm^{-2}s^{-2}$)

$$WI = \frac{dP}{dt} \cdot \frac{dU}{dt}$$

Wave intensity normalized to sample numbers (Wm^{-2})

$$WI = dP\frac{CCD}{dt} \cdot dU\frac{CCD}{dt}$$

Calculations – RV energy

RV stroke work

$$RVSW = (PAPm - RAP) \cdot RVSV$$

RV energy density

$$RV\,energy\,density = \frac{RVSW}{CSA} = \frac{(PAPm - RAP) \cdot RVSV}{RVSV \cdot HR / U_{mean}}$$

$$= \frac{(PAPm - RAP)}{HR / U_{mean}}$$

$$= (PAPm - RAP) \cdot U_{mean} \cdot CCD$$

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Participant characteristics

	Control N = 10	PAH N = 11	CTEPH N = 10
Age (yrs)	59 ± 14	56 ± 21	66 ± 9
Male, n (%)	8 (80 %)	2 (18 %)*	2 (20 %)*
BMI (kg/m²)	28 ± 5	26 ± 5	27 ± 6
HR (beats/min)	73 ± 8	81 ± 8	80 ± 15
PAPm (mmHg)	17 ± 3	47 ± 11*	42 ± 8*
TPRI (WU/m2)	7 ± 2	25 ± 13*	20 ± 8*
CI, L/min/m2	2.6 ± 0.5	2.3 ± 1.1	2.4 ± 0.8
BNP (ng/L)	50 ± 64	522 ± 141*	265 ± 166*

*p < 0.05 vs control

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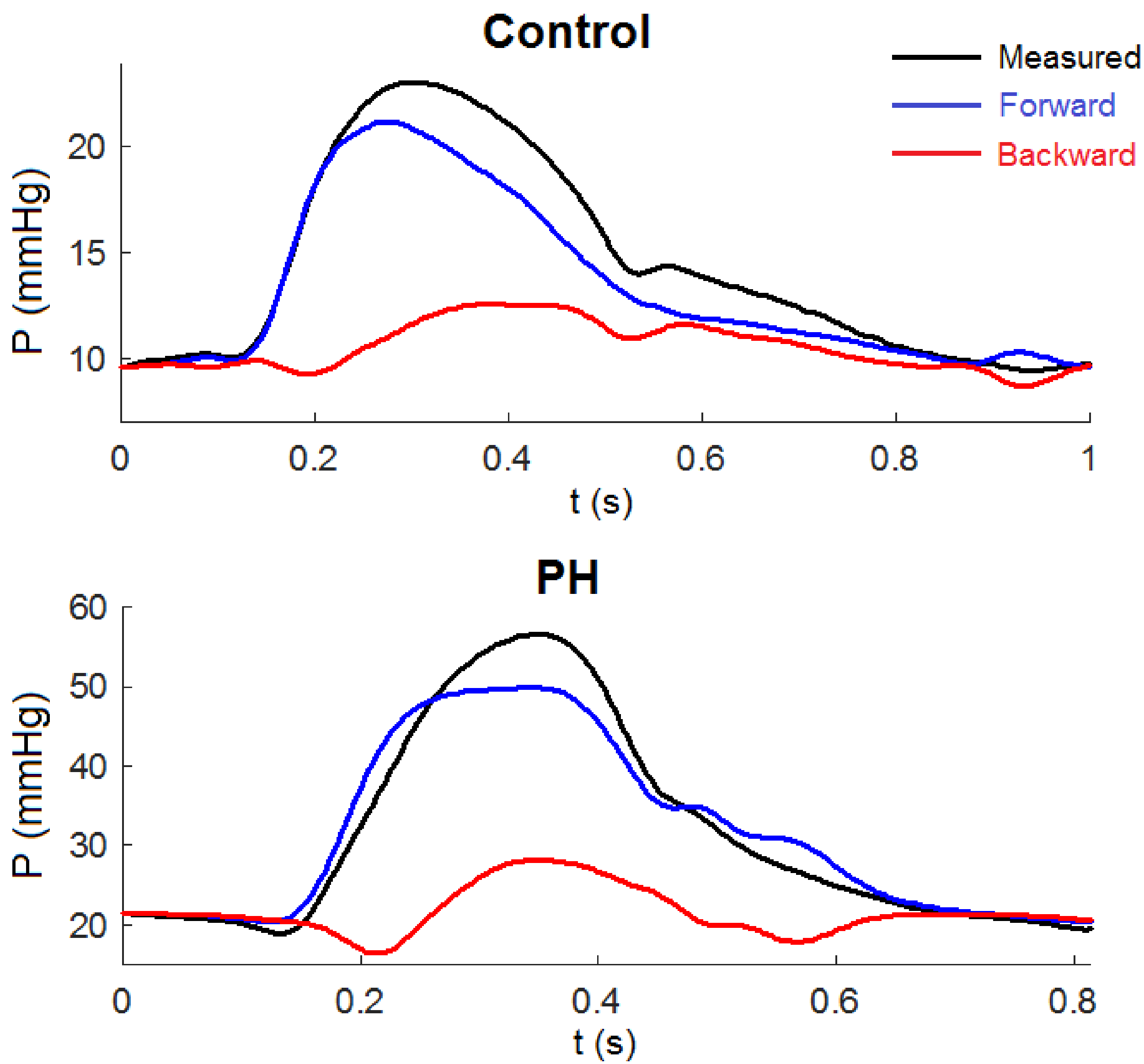
Pressure separation



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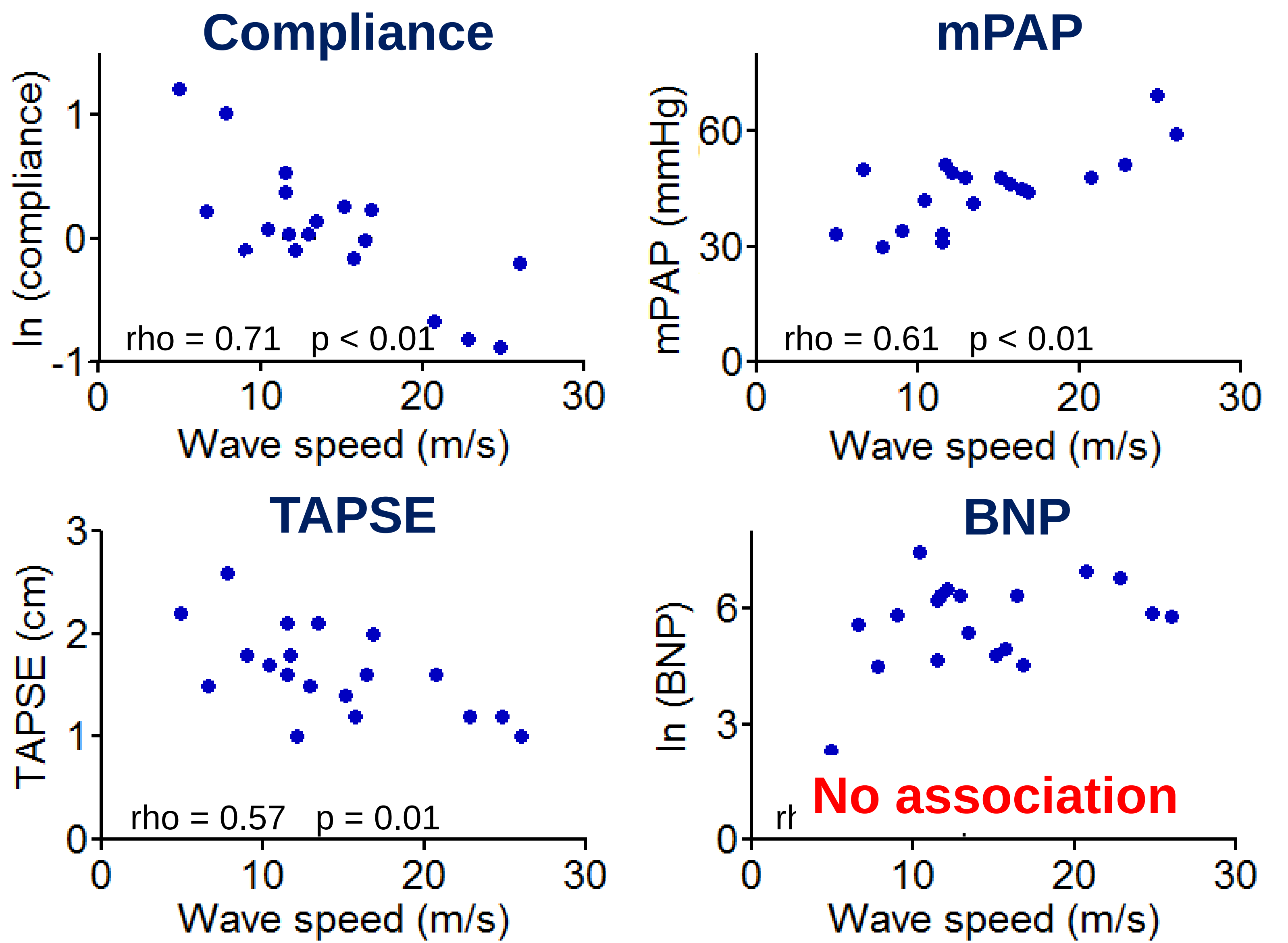
Wave speed



Wave reflection