

Automated Right Ventricular Pressure Waveform Analysis to Quantify Pulsatile Afterload Components

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Background

- Right ventricular pressure (RVP) waveform analysis provides functional insights beyond RA and PA pressures (1,2).
- Pulmonary vascular resistance (PVR) reflects only steady-state afterload; ignores pulsatile factors like compliance, wave reflections (3).
- Effective arterial elastance (Ea) summarizes afterload but cannot separate resistive, elastic, and reflective contributions (1,3)

Aim: Using simulated hemodynamic effects of pulmonary embolism in swine model, develop automated RV pressure waveform analysis to quantify pulsatile contributions to RV afterload.

Method I

- Data recorded from 3 anesthetized swine (35-40 kg) under an IACUC-approved protocol were used for the study.
- Animals were instrumented for measurement of biventricular and PA pressures and cardiac output.
- Injection of 2.5 cc thrombin activated blood clots via the right external jugular vein at ~5-minute intervals until RV systolic pressure was increased ~ 3-fold.
- Using event markers derived from the second derivative of RV pressure (1,2), the RV pressure at begin ejection, peak PA flow, and end ejection were identified. Areas within the RV pressure waveform corresponding to **total ejection area (TEA)** and the subcomponent areas of flow generation (**flow area or FA**) and flow dissipation which is regarded as the **wave reflection area (WRA)** (Figure 1).
- Pulmonary vascular compliance estimated as FA/TEA and the relative contribution of wave reflection to RV pressure during ejection calculated as WRA/FA. These values along with pulmonary vascular resistance (PVR) were referenced to Ea calculated as RV (end-systolic pressure-left ventricular end-diastolic pressure)/stroke volume.

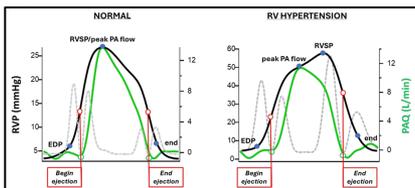


Figure 1. Illustration of identification of inflection points derived from the RVP waveform (black) relative to, pulmonary artery (PA) flow (green). The hatched line represents the second derivative of RVP squared which is used as an event marker (adapted from reference 2). **Begin ejection** is defined as the 0 point between the first and second peaks. **Peak Flow** is defined as the foot of the second peak, and **End ejection** is defined as the 0 point between the third and fourth peaks (1).

Method II

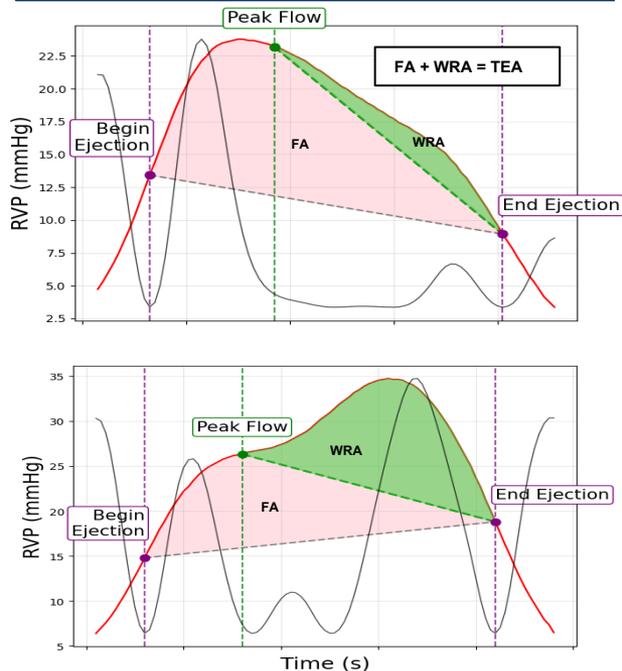


Figure 2. The pink shaded region denotes the flow area (FA). The green shaded region denotes the wave reflection area (WRA), and the combined area represents the total ejection area (TEA). The top panel shows an example with peak pressure early in the cycle and minimal wave reflection area, while the bottom panel shows a late peak and prominent wave reflection area.

Results

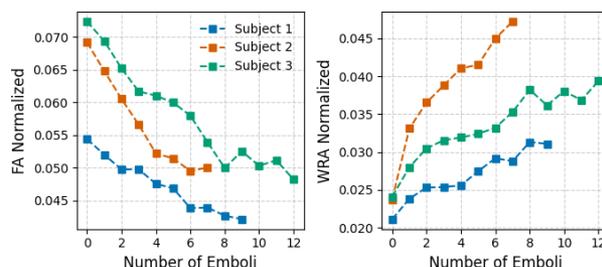


Figure 3. Flow area (FA) normalized to peak RVP (left), Wave reflection area (WRA) normalized to peak RVP (right). In 3 experiments.

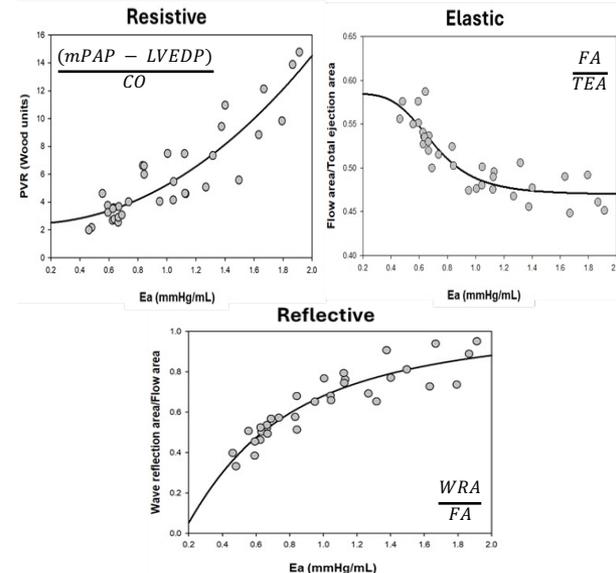


Figure 4. Relationship of effective arterial elastance (Ea) to pulmonary vascular resistance (PVR), Flow Area/Total Ejection Area (FA/TEA), and Wave Reflection Area/Flow Area (WRA/FA) across all pulmonary embolism timepoints in all three subjects.

Key Results

- Increasing clot burden results in \uparrow WRA and \downarrow FA with the resultant \uparrow WRA/FA (Figure 3)
- Ea shows strong nonlinear correlation with PVR, FA/TEA, and WRA/FA ($r > 0.80$, $P < 0.0001$) (Figure 4).
- Relative to Ea, FA/TEA (elastic component) and WRA/FA (reflective component) initially fell and rose, respectively before beginning to plateau at Ea ~1 mmHg/ml. After this PVR rose sharply indicating predominance of steady state resistance (Figure 4).

Conclusion

- Automated RV pressure waveform analysis can quantify pulsatile components of RV afterload.
- Combining waveform derived indices with PVR may provide a more complete assessment of RV afterload.
- Findings suggest an early but diminishing role of compliance and wave reflection as pulmonary load rises.

Reference/ Acknowledgment

- J Cardiothorac Vasc Anesth. 2024 Oct;38(10):2433-2445
- ESC Heart Fail. 2022 Apr;9(2):1436-1443.
- J Appl Physiol (1985). 2021 Jul 1;131(1):424-433.