Stroke Volume Estimation using Aortic Pressure Measurements and Aortic Cross Sectional Area

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Introduction

- Accurate Stroke Volume (SV) monitoring is essential for evaluating patient hemodynamic status and response to therapy. However, direct continuous SV measurements require highly invasive procedures and are not clinically feasible.
- This research presents a novel SV estimation method using measurements of aortic pressures and aortic cross sectional area. The method can be used without requiring *additionally invasive measurements* and/or *specialised devise*, and thus, has the potential for overcoming weaknesses found in current SV measuring method.

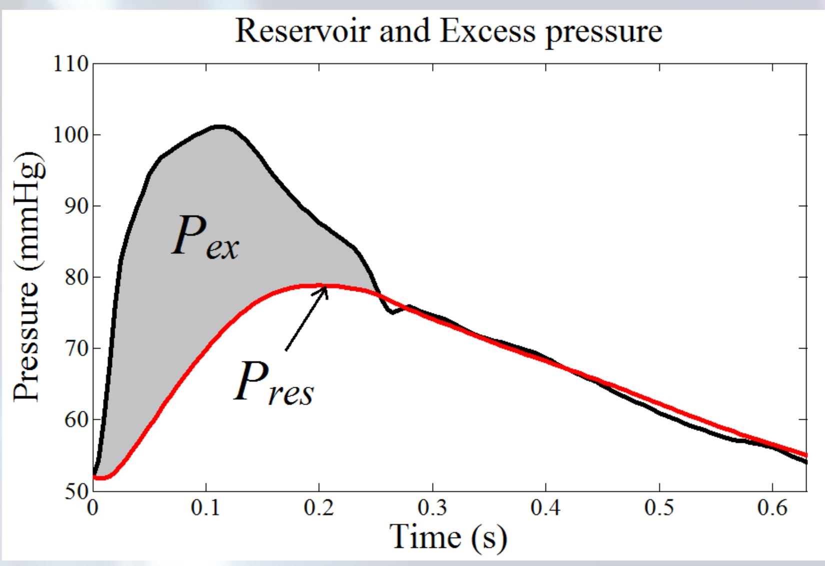
Methods

Two existing theories on blood flow in an elastic tube are applied to two spatially separated aortic blood pressure measurements to estimate beat-to-beat SV.

1. Reservoir-Excess pressure
2. Pulse Wave Propagation

Reservoir-Excess pressure

Three-element Windkessel model is used to decompose aortic pressure (*Pao*) contour into two components, reservoir pressure (*Pres*) and excess pressure (*Pex*). *Pres* represents the energy stored and released by the arterial wall. *Pex* represents the excess amount of work done by the ventricle.

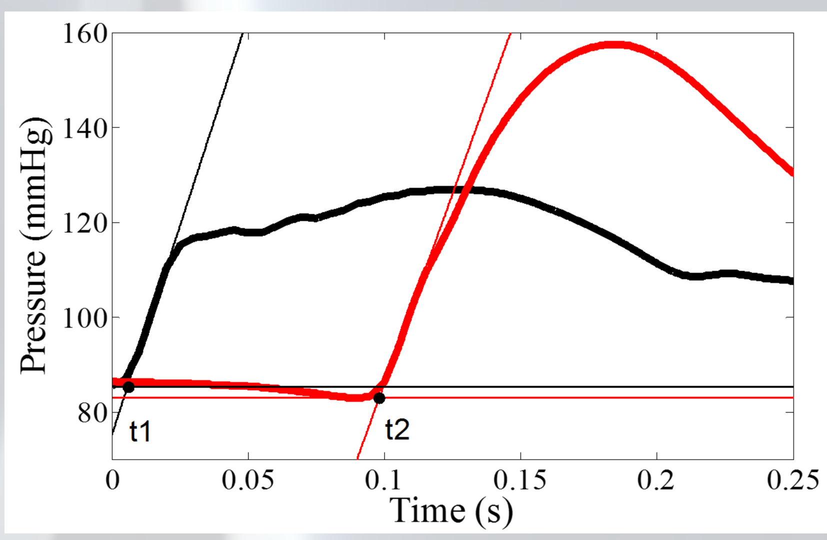


Example of separated aortic pressure waveform. *Pres* (red line), *Pex* (shaded area), and measured *Pao* (Black line).

$$P_{ao}(t) = P_{res}(t) + P_{ex}(t)$$

Pulse Wave Propagation

Pulse wave velocity can be measured from two spatially separated aortic blood pressure measurements. Transit time are determine by locating the 'foot' of the systolic rise on both pressure waveform.



Thin lines represent maximum systolic gradient line and minimum pressure line for aortic arc (thin black) and descending aortic pressure (thin red). Solid black dots represent identified 'foot' of the pressure waveforms at time t1 and t2 respectively.

Stroke Volume Estimation

Aortic impedance can be calculated from measured value of pulse wave velocity (PWV) and aortic cross sectional area (ACSA).

$$\text{Aortic impedance} = \text{density} \cdot PWV / ACSA$$

Using the identified value of aortic impedance (beat-to-beat), stroke volume can be estimated from the excess pressure component.

$$SV_{estimate} = \frac{1}{\text{aortic imedance}} \left(\int^{\text{One Heart beat}} P_{ex}(t)dt \right)$$

Validation

- Data from a porcine experiment were used to validate the method.
- Measurement of left ventricular volume, aortic arc pressure, and descending aortic pressure were made during the experiment.
- The experiment involved fluid replacement and dobutamine infusion to create changes in hemodynamic condition.
- Step-wise Positive End Expiratory Pressure (PEEP), Recruitment Manoeuver (RM) was performed to change preload condition, and to induce significant changes in SV.

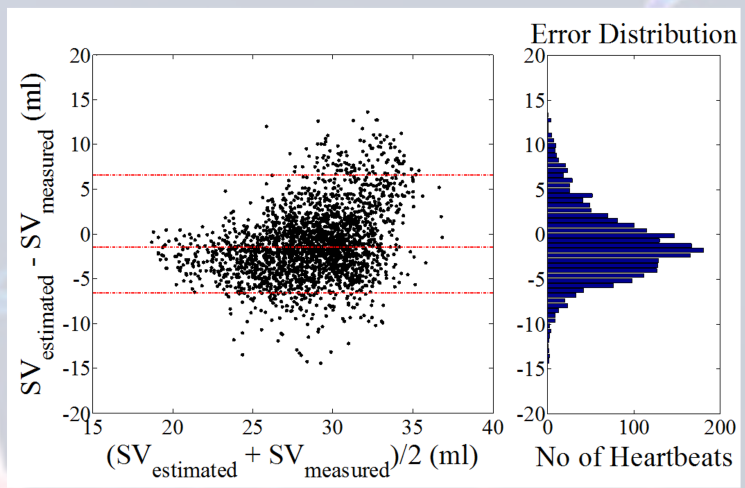
Results

Table below shows the investigated range of physiological parameters for the experiment. Mean aortic arc pressure (*MParc*), mean descending aortic pressure (*MPdec*), measured SV, pulse wave velocity (PWV), and identified aortic impedance (*Zao*) are presented as the median[5-95th percentiles].

Investigated Physiological Range

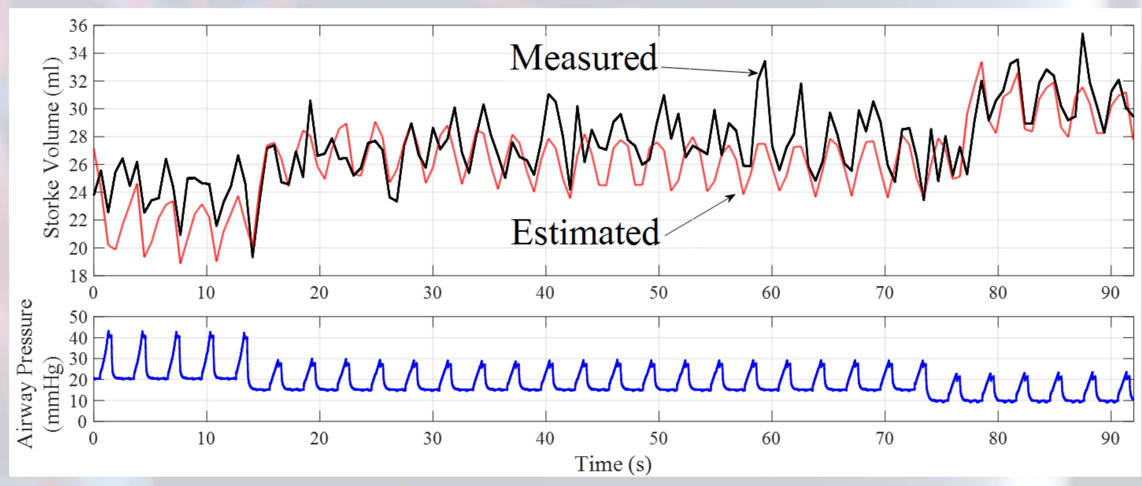
MP_{arc} (mmHg)	MP_{des} (mmHg)	$SV_{measured}$ (ml)	PWV (m/s)	Z_{ao} (mmHgs/ml)
59 [49–78]	62 [51–81]	29 [23–34]	4.5 [4.0–5.3]	0.16 [0.14–0.19]

Bland – Altman analysis was performed to show the agreements between measured SV and estimated SV. More than 2400 heartbeats were analysed.



Red dashed line shows mean, and 95% limit of agreement. Mean difference was -1.4ml and agreement was +/-6.6 ml. The analysis shows the method can accurately capture beat-to-beat SV in wide range of hemodynamic conditions.

Example of estimated SV using the method and measured SV during PEEP changes in RM are shown (time-series);



SV variation from the individual breath and SV changes made by PEEP was accurately estimated. The figure shows the method can capture cardio-pulmonary interaction between airway pressure and SV.

Conclusion

The novel SV estimation method shows accurate continuous SV can be obtained from aortic pressure measurements and aortic cross sectional area. The result showed SV can be estimated with accuracy of +/-6.6 ml while significant changes in physiological parameters are introduced. Thus, this method has the potential to improve real-time diagnosis and cardiovascular therapy in critical care environment.

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Heart Foundation

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