MODEL-BASED COMPUTATION OF TOTAL STRESSED BLOOD VOLUME FROM A PRELOAD REDUCTION EXPERIMENT

A. PIRONET*, T. DESAIVE*, J.G. CHASE**, P. MORIMONT*, P.C. DAUBY*

* GIGA-CARDIOVASCULAR SCIENCES, UNIVERSITY OF LIEGE, LIEGE, BELGIUM
** DEPARTMENT OF MECHANICAL ENGINEERING, UNIVERSITY OF CANTERBURY, CHRISTCHURCH, NEW ZEALAND

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Limited amount of data in the ICU

Difficult treatment

Cardiovascular diseases
INTRODUCTION

1 LUMPED-PARAMETER CVS MODELS

Limited amount of data in the ICU
Difficult treatment
Cardiovascular diseases
Mathematical model
Clear physiological picture
Passive vessels:

\[ P = f(V) \]
Passive vessels:

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Passive vessels:

\[ E = \frac{\Delta P}{\Delta V} \]

\[ P = E (V - V_U) \]
Passive vessels:

\[ V_S = V - V_U \]

\[ P = E V_S \]
INTRODUCTION

2 TOTAL STRESSED BLOOD VOLUME

- Total blood volume: \( \text{TBV} = \sum_i V_i \)
- Unstressed volumes: \( V_{U,i} \)

\[ V = \sum_i V_i \]

\[ V_S = V - V_U \]

- Total stressed blood volume: \( \text{SBV} = \sum_i V_{S,i} \)
INTRODUCTION

TOTAL STRESSED BLOOD VOLUME

• In engineering

![Diagram showing aortic pressure over time with labels for High SBV and Low SBV]
In medicine (Maas et al., 2012)
METHODS

CVS MODEL

- Pulmonary vein
- Left ventricle
- Aorta
- Pulmonary artery
- Right ventricle
- Vena cava

Flow resistance
Valve
PASSIVE CHAMBERS:

\[ V_S = V - V_U \]

\[ P = E V_S \]
Cardiac chambers: 

\[ P = E \; e(t) \; V_s \] 

Driver function \( e(t) \) in \([0, 1]\)
No valve:

\[
Q = \frac{P_1 - P_2}{R}
\]
Valve:

\[ Q = \begin{cases} \frac{P_1 - P_2}{R} & \text{if } P_1 > P_2 \\ 0 & \text{otherwise} \end{cases} \]
Continuity equation:

\[ V_S = Q_{\text{in}} - Q_{\text{out}} \]
METHODS

EXPERIMENTAL DATA

Pig data:
- Aortic and pulmonary artery pressures
- Ventricular pressures
- Ventricular volumes
METHODS

2

EXPERIMENTAL DATA

Inferior Vena cava
METHODS

PARAMETER IDENTIFICATION

Nominal parameter values → Subset selection algorithm → Identification of selected parameters
METHODS

PARAMETER IDENTIFICATION: STEP 1

- From the literature
- Directly from data, e.g.:

\[
SVR = \frac{MAP}{CO}
\]
PARAMETER IDENTIFICATION: STEP 2

• \( e = \text{simulations} - \text{measurements} \)
• Jacobian matrix \( J = \frac{\partial e}{\partial \rho} \)
• Hessian matrix \( H \approx J^T J \)
• Compute the eigenvalues of \( H \)
PARAMETER IDENTIFICATION: STEP 2

- Select the $r$ largest eigenvalues of $H$
- Find the corresponding parameters through a QR decomposition
- Select these $r$ parameters for optimization
METHODS

PARAMETER IDENTIFICATION: STEP 3

Using the direct search method and the initial values computed at step 1.

Nominal parameter values → Subset selection algorithm → Identification of selected parameters
RESULTS

NUMBER OF PARAMETER SELECTIONS

SBV  7/7
AE   6/7
PAE  5/7
PVR  3/7
SVR  1/7
VCE  0/7
RESULTS

PARAMETER ADJUSTMENT

Simulation
Measurement

LV pressure (mmHg)
3 RESULTS

2 PARAMETER ADJUSTMENT

Aortic pressure (mmHg) vs. Time (s)

- Simulation
- Measurement

Graph shows the comparison of aortic pressure (mmHg) measured and simulated over time (s). The graph indicates fluctuations in pressure with time, highlighting the differences between simulation and measurement.
3 RESULTS

2 PARAMETER ADJUSTMENT

Results

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Measured LV pressure</th>
<th>Measured aortic pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The method needs validation.

- With the usual way to compute SBV.
- Track SBV during vascular filling.
- Using simulated data.
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• Using simulated data.
The method could be made fully non-invasive:

- SBV is an important parameter.
  - No need for ventricular pressures.
- Change load by raising the legs.
  - No need for vena cava occlusion.
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→ No need for ventricular pressures.

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→ No need for vena cava occlusion.
• Model-based method to compute SBV from preload reduction data.

• SBV is an important parameter

If validated, the method could provide a non-invasive way to track SBV.
Model-based method to compute SBV from preload reduction data.

SBV is an important parameter

If validated, the method could provide a non-invasive way to track SBV.
• Model-based method to compute SBV from preload reduction data.

• SBV is an important parameter if validated, the method could provide a non-invasive way to track SBV.
Thanks for your attention! Questions?
METHODS

EXPERIMENTAL DATA

Pulmonary vein → Left ventricle → Aorta → Vena cava → Right ventricle → Pulmonary artery

Flow resistance

Valve

Tricuspid valve resistance
METHODS

EXPERIMENTAL DATA

Pulmonary vein → Pulmonary artery → Right ventricle → Tricuspid valve resistance → Vena cava → Flow resistance

Right ventricle → Left ventricle → Aorta ➔ Valve

Vena cava ➔ Flow resistance → Pulmonary vein
RESULTS

SBV VERSUS WEIGHT

Weight (kg) vs SBV (ml)

- 15 ml/kg
- 27 ml/kg

Weight (kg):
- 400
- 900

SBV (ml):
- 28
- 36

SBV (ml/kg):
- 15
- 27