Noninvasive cardiac output estimation from peripheral pressure and pulse wave velocity: A model-based study

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Cardiac output monitoring

**Importance.** CO monitoring is essential for patient management in the operating room and the ICU.

-> valuable information on global perfusion

**Gold standard.** Thermo-dilution using a pulmonary artery catheter set the basis for CO monitoring in clinical practice.

*Figure 1.* Pulmonary artery catheter positioning and corresponding pressure waveforms in mmHg. Source: www.derangedphysiology.com, The Pulmonary Artery Catheter
Noninvasive monitoring & Challenges

**Pressure pulse analysis techniques** (some have been commercialized)

- still based on invasive recordings or they require invasive calibration

**Thoracic bioimpedance**

- interference with electrocautery
- patient’s movement
- arrhythmias may affect its accuracy

**Photoelectric plethysmography**

- simplified assumptions that can be unreliable
- not adequately validated in human

Figure 2. Pulse contour CO monitoring method

Figure 3. PPG monitoring system
Motivation

Inter-subject variability requires theory-based CV models to be as individualized as possible (age, gender, hypertension, etc.).

**Our approach:**

To tune a 1-D arterial tree model to patient-specific standards using only noninvasive, easily-obtained peripheral measurement data.
Mathematical model of the cardiovascular system

- 103 arterial segments
- 1-D model of the vasculature: solves 1-D Navier-Stokes equations
- Local area compliance: $C_A(\text{pressure, location})$ [Langewouters et al.]
- 3WK coupled to the terminal sites
- Aortic flow input

Figure 4. Schematic representation of the arterial tree, adopted from Reymond et al.


G. J. Langewouters, Visco-elasticity of the Human Aorta in Vitro in Relation to Pressure and Age. 1982.
Two-layer optimization algorithm to tune the 1-D model to patient-specific standards
In vivo validation

- **In vivo anonymized data** (Mobil-O-Graph – derived brachial pressure, cf-PWV) from n=20 subjects (Age : 23 – 70) by Papaioannou et al.

<table>
<thead>
<tr>
<th></th>
<th>min</th>
<th>max</th>
<th>mean</th>
<th>SD</th>
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<tbody>
<tr>
<td>Central aortic SBP (mmHg)</td>
<td>83</td>
<td>154</td>
<td>124</td>
<td>14.78</td>
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<tr>
<td>Peripheral SBP (mmHg)</td>
<td>96</td>
<td>156</td>
<td>120.20</td>
<td>16.31</td>
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<tr>
<td>Peripheral DBP (mmHg)</td>
<td>31</td>
<td>95</td>
<td>76.05</td>
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<td>Peripheral PP (mmHg)</td>
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<td>MAP (mmHg)</td>
<td>72.67</td>
<td>115.33</td>
<td>90.77</td>
<td>10.83</td>
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<td>Mean aortic flow (L/min)</td>
<td>3</td>
<td>6.20</td>
<td>4.34</td>
<td>14.69</td>
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<td>HR (bpm)</td>
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<td>98</td>
<td>70.90</td>
<td>10.04</td>
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<tr>
<td>cf-PWV (m/s)</td>
<td>5.25</td>
<td>11.25</td>
<td>6.89</td>
<td>1.92</td>
</tr>
</tbody>
</table>

Table 1. Descriptive characteristics of the in vivo measurement data

Results

Figure 6. Scatter plot between the “real” CO values from the in vivo data and the model-derived CO estimates (solid line represents equality).

Figure 7. Scatter plot between the “real” cSBP values from the in vivo data and the model-derived cSBP estimates (solid line represents equality).

RMSE = 4.36 mmHg

RMSE = 0.38 L/min
Discussion

• The successful tuning of a 1-D model of the vasculature can be achieved by using noninvasive, easily-obtained peripheral measurement data.

• However, tuning is successful when we take into account additional characteristics of the subject (age, hypertension). Uniform changes in compliance don’t apply to hypertensive and the elderly.

• Further validation against a large in vivo database will allow us to conclude that our method can potentially be employed for noninvasive monitoring in the clinical setting.
Thank you very much!