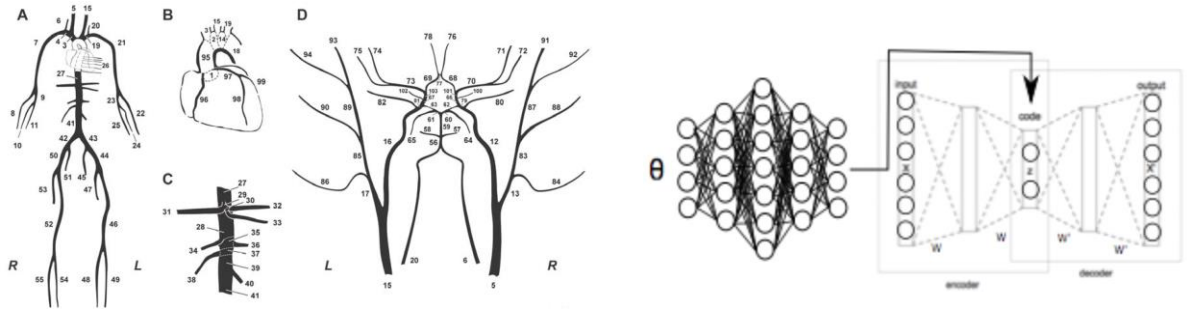
Noninvasive cardiac output estimation from peripheral pressure and pulse wave velocity: A model-based study



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ARTERY
Association for Research into Arterial Structure and Physiology

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.

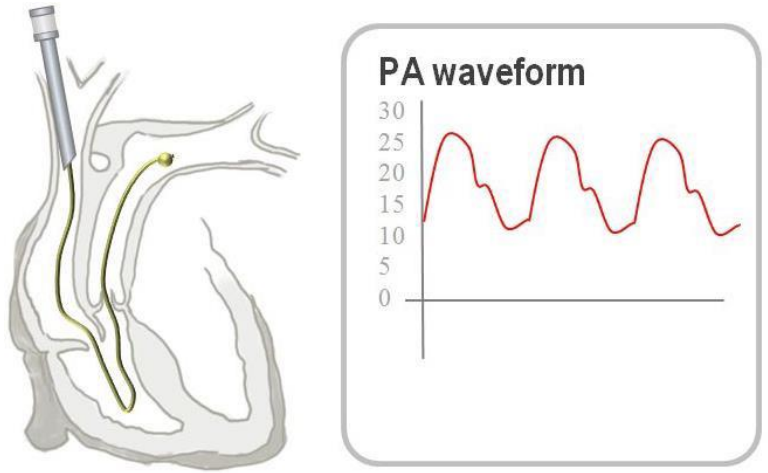


Figure 1. Pulmonary artery catheter positioning and corresponding pressure waveforms in mmHg. Source: www.derangedphysiology.com, The Pulmonary Artery Catheter

Noninvasive monitoring & Challenges

Pressure pulse analysis techniques (some have been commercialized)

x still based on invasive recordings or they require invasive calibration

Thoracic bioimpedance

x interference with electrocautery
x patient's movement
x arrhythmias may affect its accuracy

Photoelectric plethysmography

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

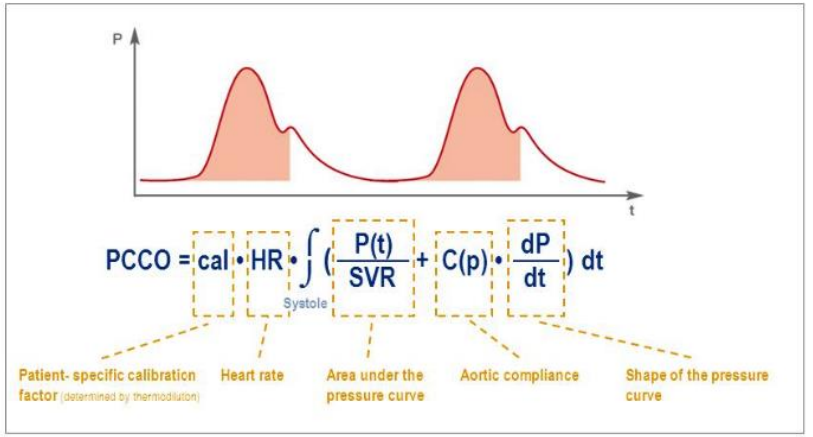


Figure 2. Pulse contour CO monitoring method

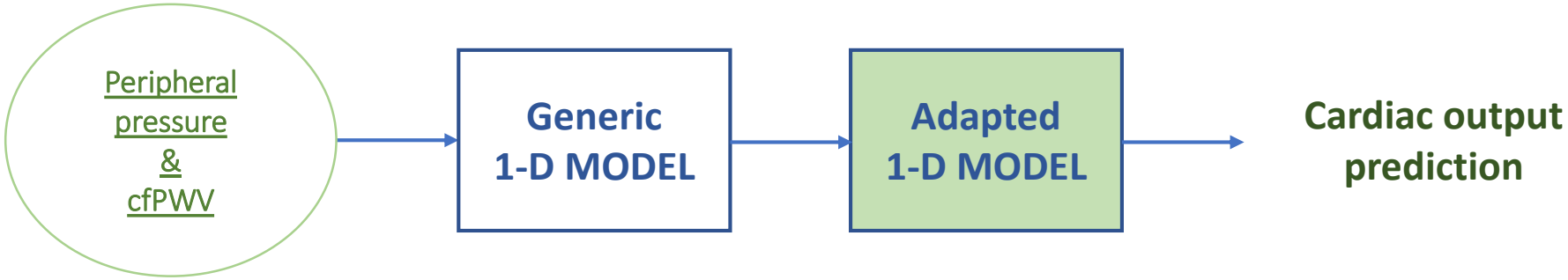
Figure 3. PPG monitoring system

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

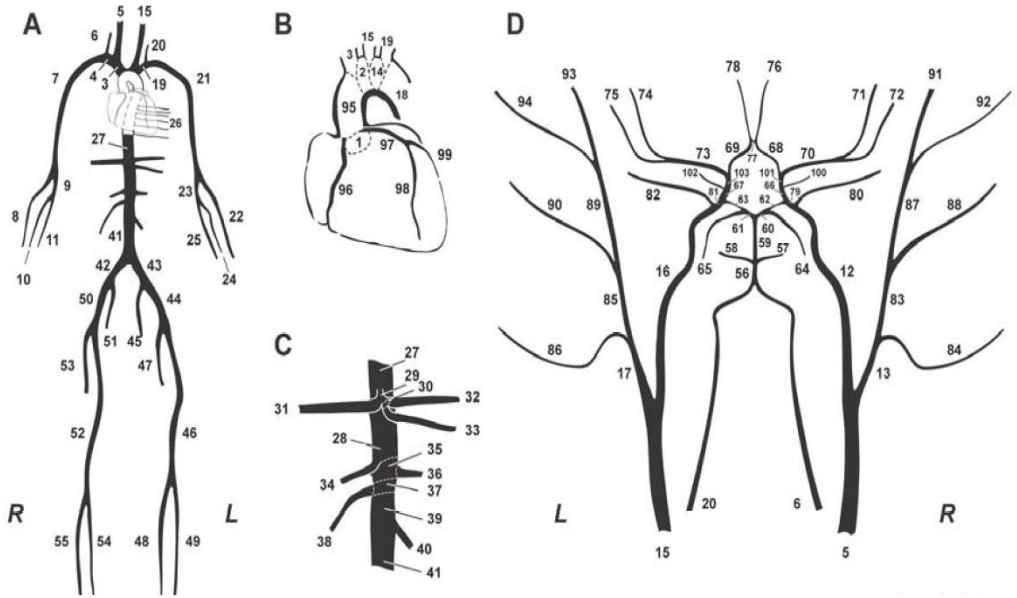


Figure 4. Schematic representation of the arterial tree, adopted from Reymond et al.

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

P. Reymond, F. Merenda, F. Perren, D. Rüfenacht, and N. Stergiopulos, "Validation of a one-dimensional model of the systemic arterial tree," Am. J. Physiol. Heart Circ. Physiol., vol. 297, no. 1, pp. H208-222, Jul. 2009.

G. J. Langewouters, Visco-elasticity of the Human Aorta in Vitro in Relation to Pressure and Age. 1982.

Methods

Two-layer optimization algorithm to tune the 1-D model to patient-specific standards

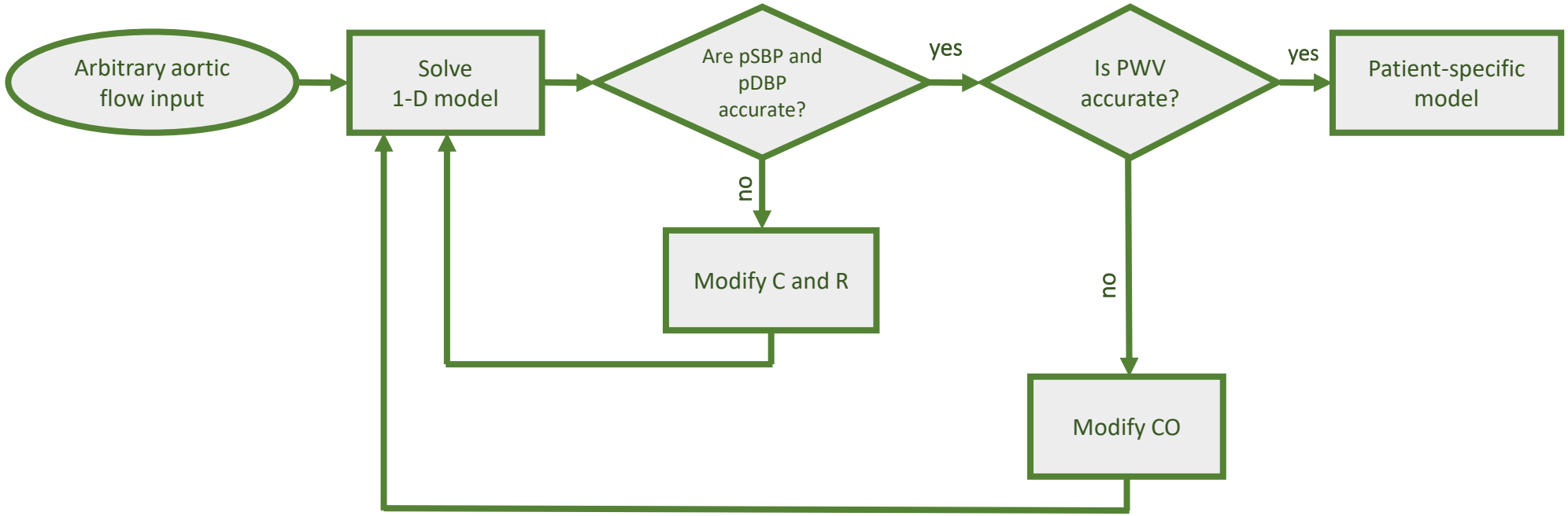


Figure 5. Schematic representation of the inverse method for noninvasive CO prediction

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.

Descriptive hemodynamic characteristics

	min	max	mean	SD
Central aortic SBP (mmHg)	83	154	124	14.78
Peripheral SBP (mmHg)	96	156	120.20	16.31
Peripheral DBP (mmHg)	31	95	76.05	8.87
Peripheral PP (mmHg)	36	61	44.15	10.38
MAP (mmHg)	72.67	115.33	90.77	10.83
Mean aortic flow (L/min)	3	6.20	4.34	14.69
HR (bpm)	51	98	70.90	10.04
cf-PWV (m/s)	5.25	11.25	6.89	1.92

Table 1. Descriptive characteristics of the *in vivo* measurement data

T. G. Papaioannou et al., "First in vivo application and evaluation of a novel method for non-invasive estimation of cardiac output," Med Eng Phys, vol. 36, no. 10, pp. 1352–1357, Oct. 2014.

Results

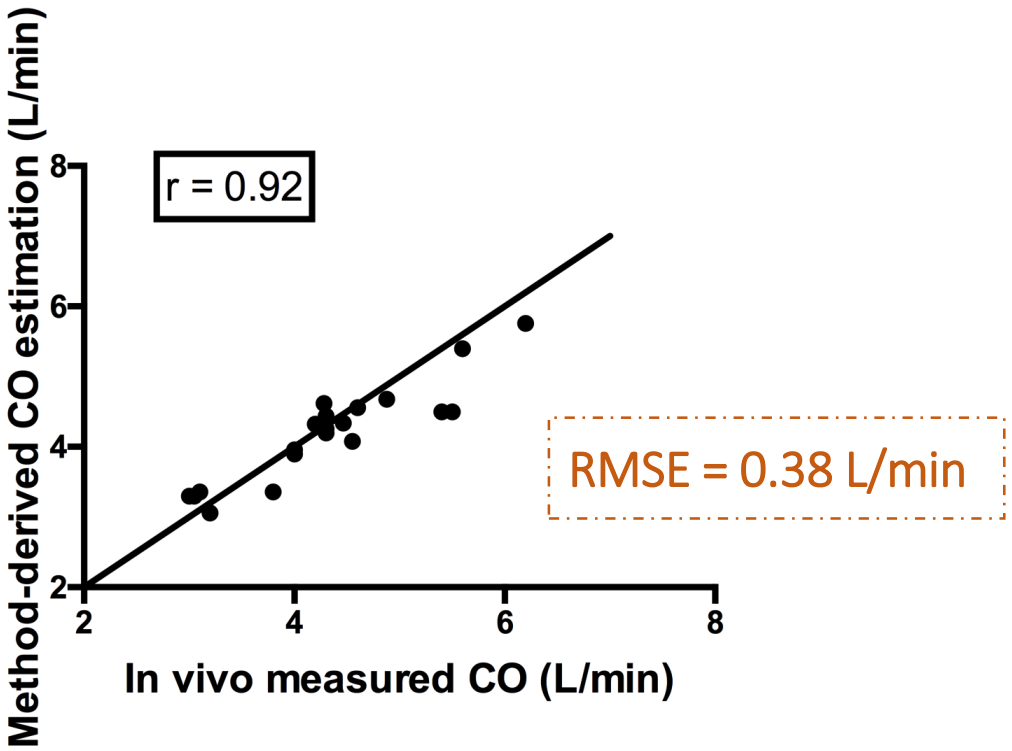


Figure 6. Scatter plot between the "real" CO values from the *in vivo* data and the model-derived CO estimates (solid line represents equality).

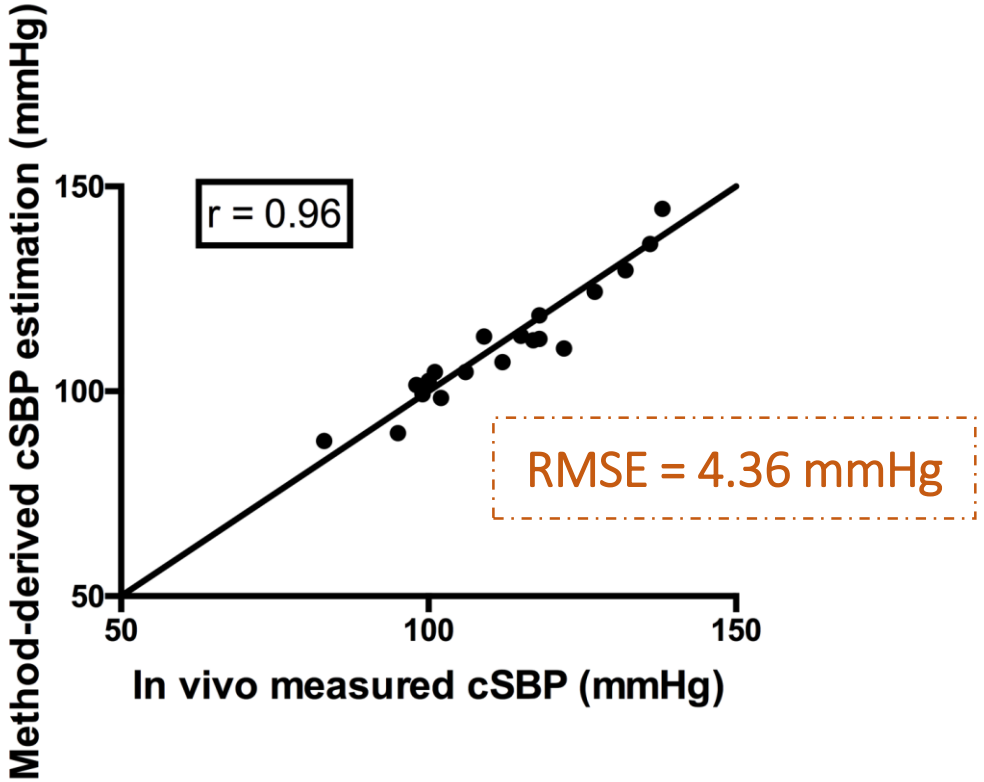


Figure 7. Scatter plot between the "real" cSBP values from the *in vivo* data and the model-derived cSBP estimates (solid line represents equality).

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!