A comparison of reduced-order computational models for central blood pressure estimation

J. Mariscal-Harana[1], P. H. Charlton[1], S. Vennin[1], A. van Engelen[1], T. Schneider[2], M. Florkow[1,2], H. de Bliek[3], B. Ruijsink[1], I. Valverde[1], M. Charakida[1], K. Pushparajah[1], S. Sherwin[4], R. Botnar[1], J. Alastruey[1]

[1] School of Biomedical Engineering and Imaging Sciences, King's College London, London, UK; [2] Philips Healthcare, Guildford, UK; [3] HSDP Clinical Platforms, Philips Healthcare, Best, The Netherlands; [4] City and Guilds Building, South Kensington Campus, Imperial College London, London, UK

SUMMARY

PROBLEM

Gold standard central blood pressure (CBP) measurements require an invasive catheterisation, which is risky and costly.

AIM

Create an aortic model which accurately estimates CBP from non-invasive aortic magnetic resonance imaging (MRI) and peripheral pressure.

OBJECTIVES

1. **Identify** optimal haemodynamic parameter estimation methods.
2. **Compare** the performance of 0-D/1-D models for estimating CBP.

OUTCOME

Our **1-D aortic model** initial clinical assessment showed mean absolute errors of **2** and **7 mmHg** for estimated **systolic** and **pulse** CBP, respectively.

Our 1-D aortic model increases the functionality of cardiac MRI scans by providing an accurate estimate of CBP

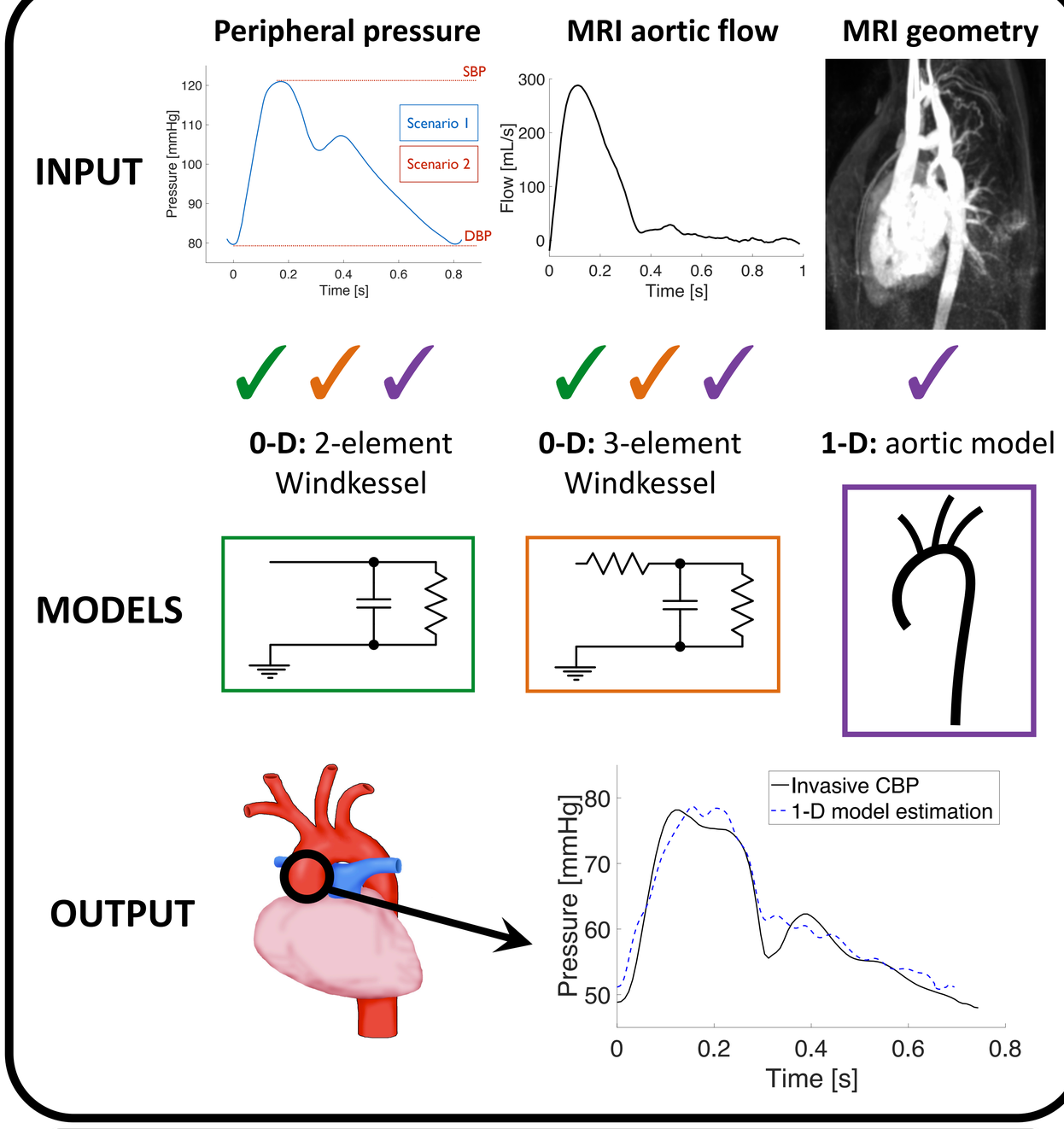
Courtesy of PHILIPS Healthcare

1. Clinical superiority of CBP

*CBP is a **better cardiovascular risk indicator** than brachial pressure*[1]

[1]McEniery et al. (2014). *Eur Heart J*, 35(26), 1719–1725

2. CBP estimation: 0-D/1-D models



3.1. Parameter estimation

- We **identified** optimal methods for the estimation of haemodynamic parameters by testing them on a virtual (computed) cohort (*n* = 20).
- We accounted for two common clinical scenarios:
  - Scenario 1: A peripheral pressure waveform is available.
  - Scenario 2: Only diastolic and mean pressures are available.

Virtual cohort: 20 healthy subjects

- 20 subjects generated from a 1-D model of the systemic arteries[2].
- Individual cardiovascular parameter variations from the clinical literature for healthy humans.

Optimal parameter estimation methods

Parameter	Formula	Scenario	Error (%)
End-systolic time, t_s	Maximum or x-axis crossing, from Q	1, 2	0.0 ± 0.1
Outflow Pressure, P_{out}	Decay time method, $t = t_s$	1	8.3 ± 12.8
	0	2	100.0 ± 0.0
Arterial Resistance, R_T	$(\overline{P} - P_{out})/\overline{Q}$	1	0.4 ± 0.1
	$(DBP + 0.4PP - P_{out})/\overline{Q}$	2	3.8 ± 0.9
Arterial Compliance, C_T	Decay time method, $t = t_s$	1	2.5 ± 2.1
	DBP iterative method	2	6.4 ± 1.9
Pulse Wave Velocity, c	Least-squares: asc-desc aorta, from Q	1, 2	8.7 ± 3.9
Aortic Impedance, Z_0	$0.05\ R_T$	2	26.9 ± 20.1

[2]Willemet et al. (2015). *Am J Physiol-Heart C*, *309*(4), H663–H675

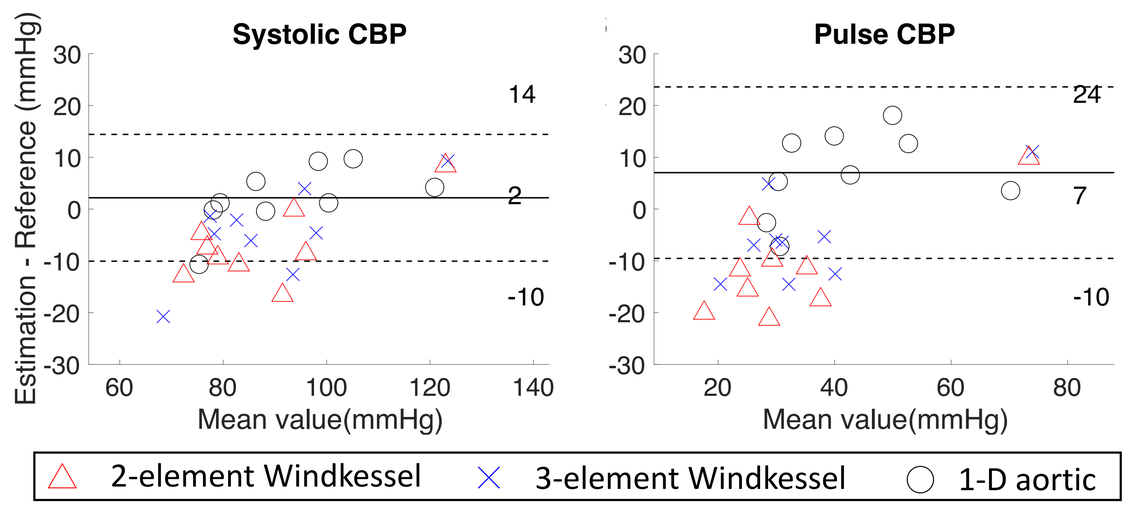
3.2. CBP estimation: 1-D vs 0-D models

- We **estimated** CBP on a clinical cohort (*n* = 9) using two-element (2-el) and three-element (3-el) Windkessel models and our 1-D aortic model.
- We **compared** CBP estimates against invasive CBP measurements.

Clinical cohort: 9 post-coarctation repair patients

- PC-MRI aortic flow and aortic geometry.
- Invasive CBP available for comparison.

Systolic and pulse CBP for 9 post-coarctation repair patients



Absolute error (mean ± SD):	2-el Windkessel	3-el Windkessel	1-D aortic
Systolic [mmHg]	6.9 ± 7.4	4.3 ± 8.7	2.2 ± 6.1
Pulse [mmHg]	11.0 ± 9.8	5.6 ± 8.6	7.0 ± 8.3

4. Conclusions

- We have **identified** the best methods for individual cardiovascular parameter estimation in two clinical scenarios.
- Our 1-D aortic model provides more accurate and precise systolic and pulse CBP estimates **compared** to 0-D models.

5. Future work

- Increase the number of virtual subjects through **simultaneous cardiovascular parameter variations**.
- Apply optimal parameter estimation methods to calculate **0-D outflow boundary conditions** of the 1-D aortic model.

JMH gratefully acknowledges the support of a PhD Fellowship awarded by the King's College London and Imperial College London EPSRC Centre for Doctoral Training in Medical Imaging. This research was supported by the National Institute for Health Research (NIHR) Biomedical Research Centre award to Guy's and St Thomas' NHS Foundation Trust in partnership with King's College London, and by the NIHR Healthcare Technology Cooperative for Cardiovascular Disease at Guys and St Thomas' NHS Foundation Trust. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health.