A Database for Developing Pulse Wave Analysis Algorithms

Peter H Charlton [1], Jorge Mariscal Harana [1], Samuel Vennin [1 2], Phil Chowienczyk [2], Jordi Alastruey [1]

[1] Department of Biomedical Engineering, [2] Department of Clinical Pharmacology; King's College London, King's Health Partners, St Thomas' Hospital, London, UK

Summary

Motivation: it is difficult and costly to acquire comprehensive datasets with which to assess the performance of pulse wave (PW) analysis algorithms.

Aim: to create a database of simulated PWs under a range of cardiovascular conditions, representative of a healthy population.

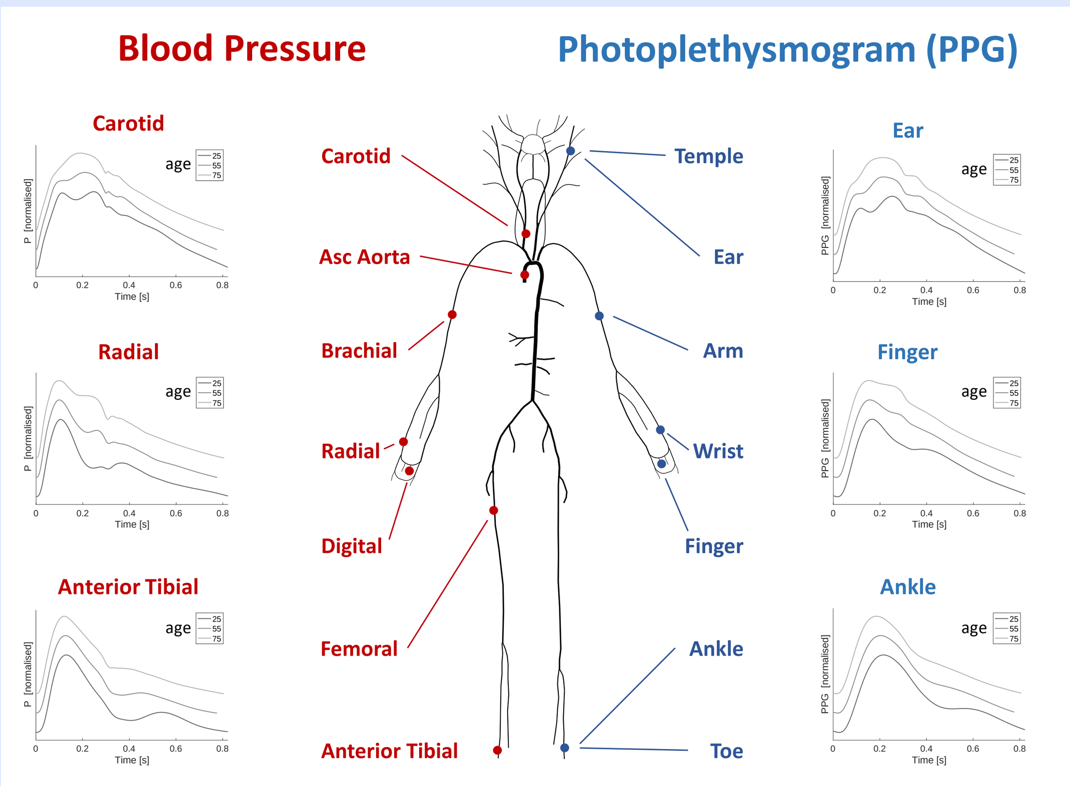
Methods: Pulse waves were simulated for healthy adult subjects of different ages with a range of cardiovascular properties. Pressure, flow, area and photoplethysmographic PWs were simulated at common measurement sites.

Results: The database was verified through comparison with *in vivo* PWs. Changes in haemodynamics and PW shape with age were well reproduced.

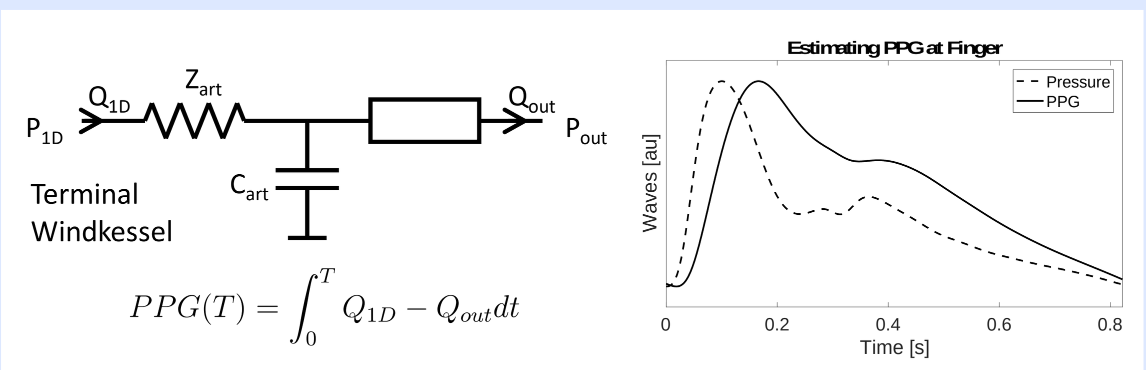
Conclusion: The database is a valuable resource for development and pre-clinical assessment of PW analysis algorithms.

Methods

Simulating Pulse Waves
We used a 1-D model of pulse wave propagation to simulate arterial PWs. The model consists of a prescribed aortic flow wave, a network of the larger arteries, and terminal Windkessel boundary conditions to model vascular beds [1].



Adapted from [1]



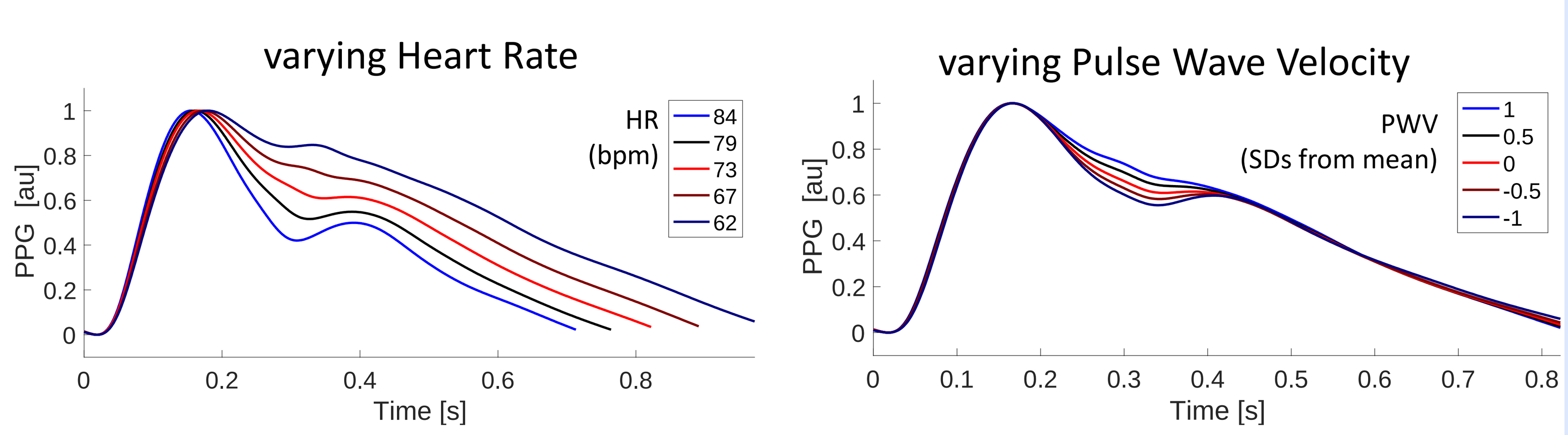
$$PPG(T) = \int_0^T Q_{1D} - Q_{out}\,dt$$

Adapted from [2]

Photoplethysmogram (PPG) waves were simulated as the vascular bed blood volume (left) at the terminal Windkessels.

Changes with age and normal variation: PWs were simulated for 258 virtual healthy adults aged 25 to 75 by adjusting model input parameters in line with *in vivo* data from the literature (see above figure) [2]. In addition, PWs were simulated for a set of subjects at each age by varying the input parameters in line with normal physiological variation (see below).

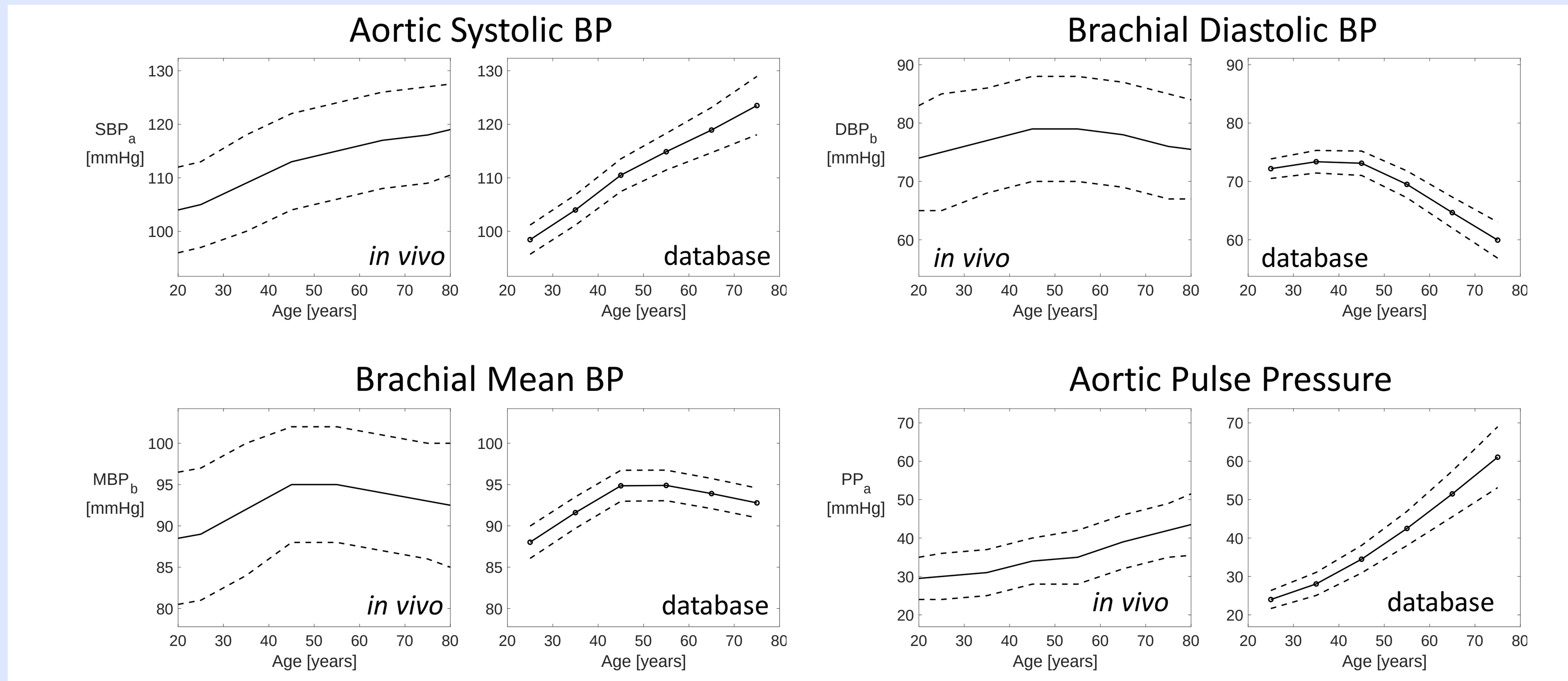
Changes in 25-year old finger PPG waves with normal variation



Adapted from [3]

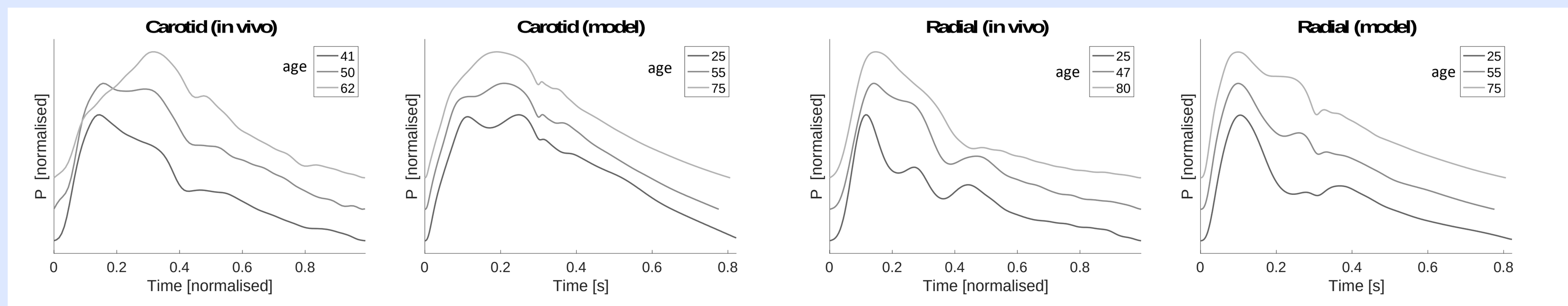
Results

Comparison with *in vivo* haemodynamics
The haemodynamics extracted from the simulated PWs exhibited similar trends to those measured *in vivo*, as shown below.



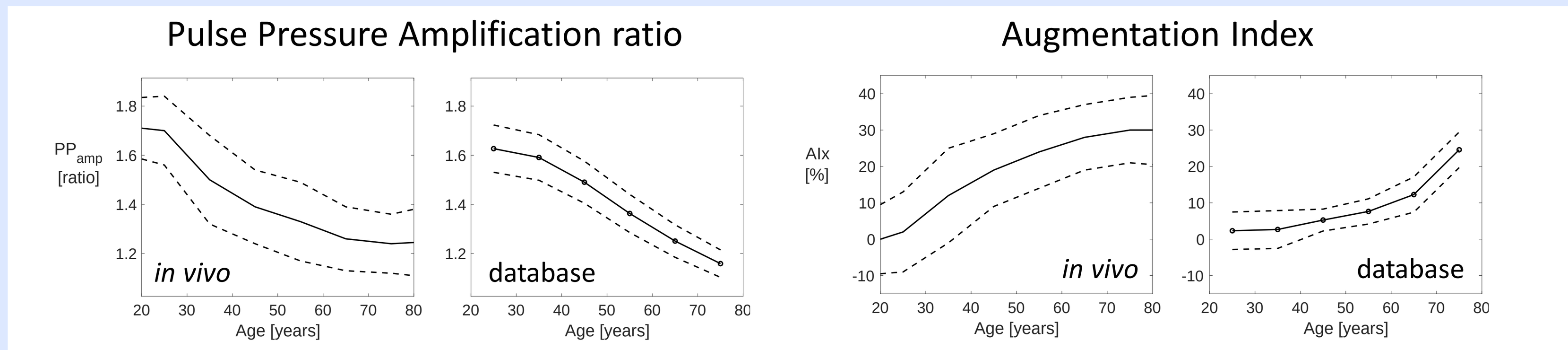
Adapted from [2]

Comparison with *in vivo* pulse waves
Similar changes in PW shape with age were observed between simulated and *in vivo* data, as shown below.



Adapted from [2]

Furthermore, similar changes in PW propagation with age were observed between simulated and *in vivo* data, as shown below.

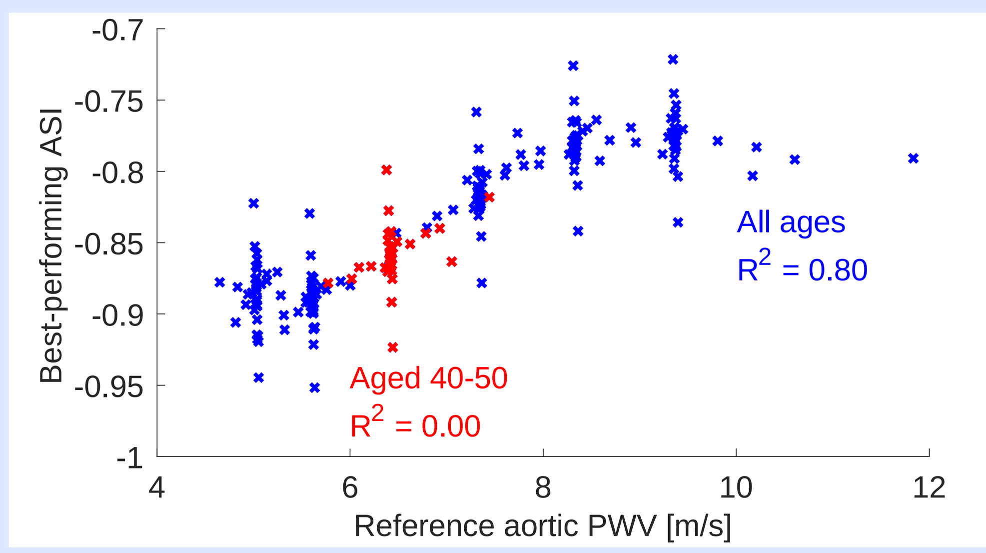


Adapted from [2]

Developing algorithms

Developing arterial stiffness indices (ASIs)
Arterial stiffness is a valuable marker for cardiovascular risk. Several algorithms have been proposed to estimate arterial stiffness from the shape of peripheral PWs. The dataset is being used to assess the performance of arterial stiffness indices (ASIs) *in silico*, and to develop novel ASIs.

Initial results



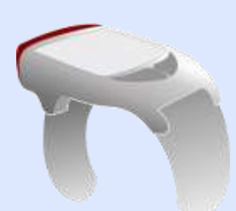
Source: [3]

ASIs have been reported to correlate well with aortic stiffness. However, results from the database (left) suggest performance may be reduced when considering only a certain age range. Here, this was due to other cardiovascular properties other than aortic stiffness influencing the ASI.

Next Steps

1. Extend the dataset to represent a sample of healthy adults.

2. Make the dataset freely available.



3. Use the dataset to develop algorithms suitable for use in smart wearables.

[1] Charlton, P. H. *et al.,* Assessing mental stress from the photoplethysmogram: a numerical study. *Physiological Measurement*, *39*(5), 054001, 2018. DOI: 10.1088/1361-6579/aabe6a . CC BY 3.0

[2] Charlton, P. H. *et al.,* Modelling arterial pulse wave propagation during healthy ageing. *World Congress of Biomechanics*, Dublin, Ireland, 2018.

[3] Charlton, P. H. *et al.,* A numerical assessment of methods to estimate aortic stiffness from arterial pulse waves. *World Congress of Biomechanics*, Dublin, Ireland, 2018. DOI: 10.5281/zenodo.1311197 . CC BY 4.0

Acknowledgments: This work was supported by the British Heart Foundation [PG/15/104/31913] and the Wellcome EPSRC Centre for Medical Engineering at King's College London [WT 203148/Z/16/Z]. The views expressed are those of the authors and not necessarily those of the British Heart Foundation, Wellcome Trust or EPSRC.

King's College London

Peter.Charlton@kcl.ac.uk