Modelling arterial pulse wave propagation during healthy ageing

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INTRODUCTION

The arterial pulse wave is influenced by the heart and the vasculature, making it a rich source of information on cardiovascular health. It has been proposed that several cardiovascular properties such as arterial stiffness could be assessed by extracting indices from the pulse wave. One-dimensional computational modelling is a valuable tool for designing pulse wave indices, since it allows indices to be measured under controlled conditions. The aim of this study was to enhance the utility of such models by incorporating the effects of ageing, and by simulating the photoplethysmogram (PPG) pulse wave.

METHODS

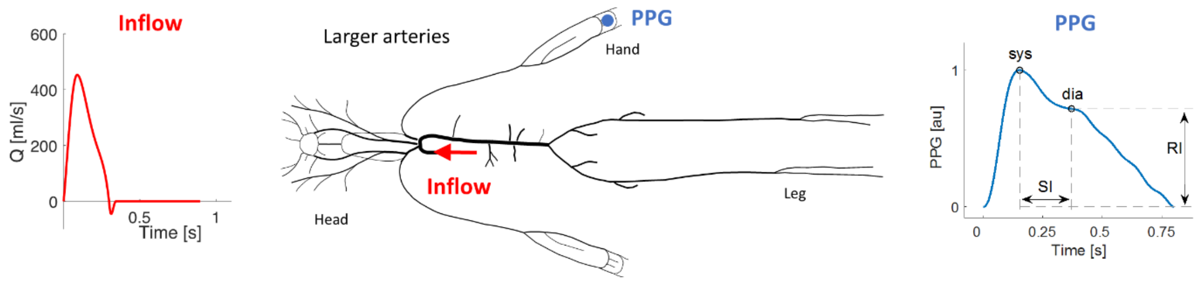
A baseline model of arterial haemodynamics in a young, healthy subject was constructed using the nonlinear one-dimensional equations of incompressible and axisymmetric flow in Voigt-type visco-elastic vessels (see Figure). Baseline parameters were adapted from [1, 2]. Flow from the left ventricle into the aortic root was modelled using a periodic inflow boundary condition. The larger arteries of the head, limbs and thoracic and abdominal organs were modelled as thin, deformable cylindrical tubes. Vascular beds were modelled using matched Windkessel boundary conditions. A literature review was conducted to determine the effects of ageing on the model parameters. The reported changes with age in heart rate, stroke volume and ejection time were incorporated by modifying the aortic inflow wave. Changes in arterial stiffness, diameter and length were included in the arterial network parameters. Changes in systemic vascular resistance and compliance were incorporated into the Windkessel boundary conditions. PPG signals were simulated using a transfer function relating blood pressure to PPG. Simulations of pulse wave propagation were then conducted for virtual subjects ranging from young to elderly adults. Several simulations were conducted at each age by varying the parameters in line with typical inter-subject variations in cardiovascular physiology.

RESULTS

The model was verified through qualitative and quantitative comparison of simulated pulse waves and haemodynamic parameters with *in vivo* measurements. The potential utility of the model was demonstrated by assessing the cardiovascular determinants of two PPG pulse wave indices which are used to estimate large artery stiffness: the stiffness and reflection indices. Both indices were found to be influenced by arterial stiffness as expected, as well as a range of additional unrelated cardiovascular parameters.

CONCLUSION

We have created a model of pulse wave propagation which incorporates healthy ageing and normal physiological variations. This model will be useful for developing novel pulse wave indices derived from PPG pulse waves, which can be easily acquired using a pulse oximeter or smartphone.



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