Heart beat pulse damping due to arterial expansion

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INTRODUCTION

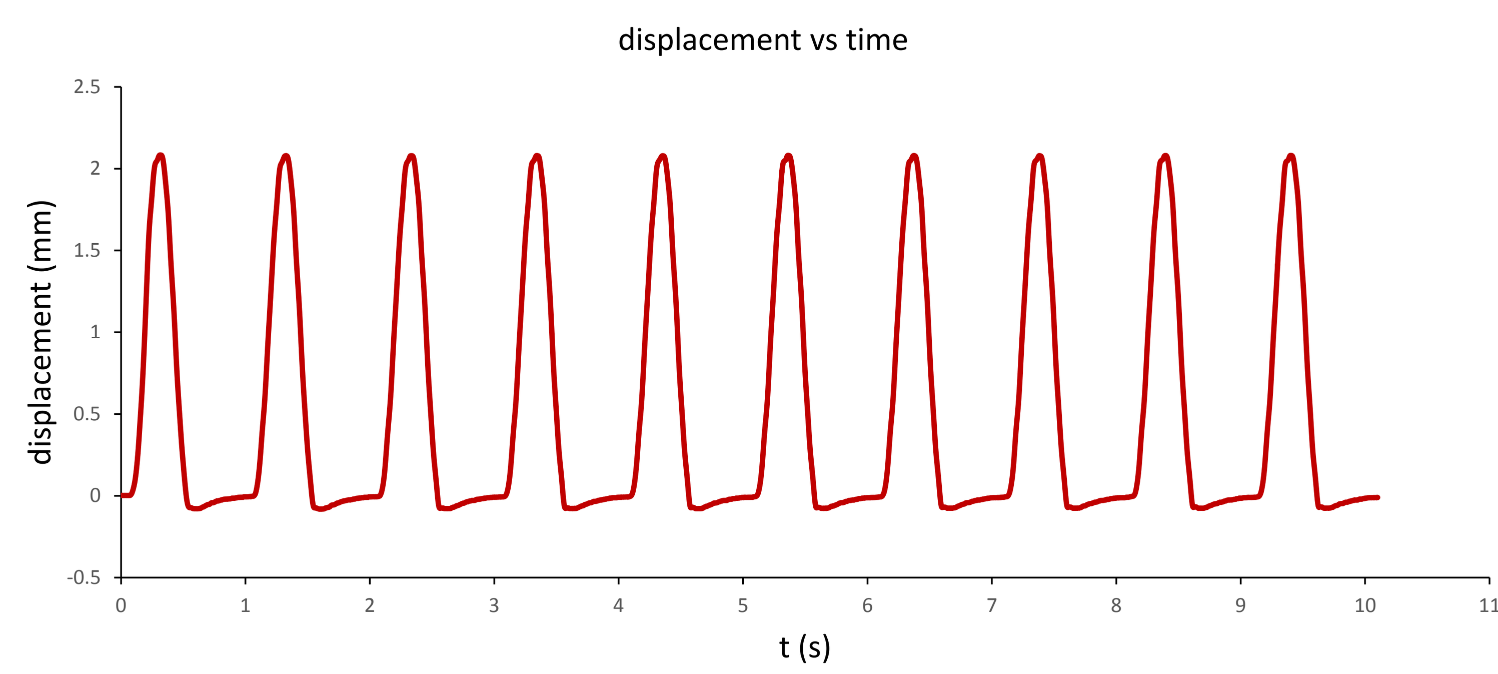
Recent evidence suggests a link between cardiovascular and neurodegenerative disease. The cause of cerebral micro-bleeds remains unresolved, though associations have been made with aortic stiffness, increased pulse wave velocity, and aging. Indeed, changes in pulsatile shear stress provoked by arterial stiffening inherent to the aging process, or indirect flow effects on the immunological system, extend to the brain, an organ with low peripheral resistance.

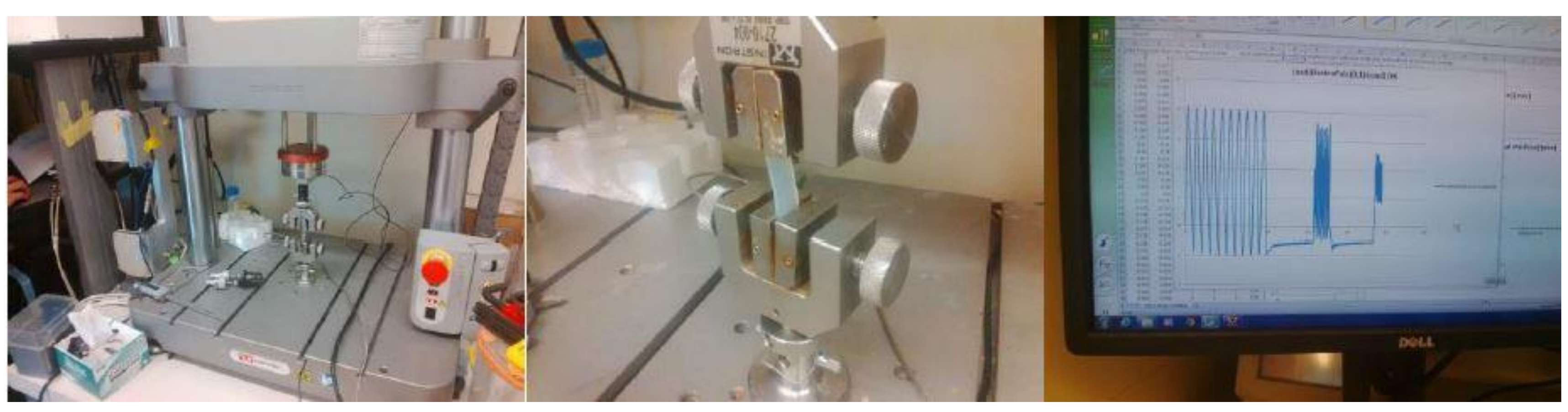
The aim of this research is to create a mathematical model showing how stiff arteries do not dump pulse wave with input data from experiments where arterial models are expanded in a controlled atmosphere.

MATERIALS AND METHODS

In order to implement tests in a lab environment different materials are analysed to perform pulse flow monitoring. PDMS and ePTFE tubes were chosen for this study. Tubes were cut and subjected to cycles of expansion up to values of 10, 20, 30, 40 and 50% deformation at 1[Hz.]. Tests were carried out using sinusoidal waves of frequencies of 1, 5 and 10[Hz] to obtain a proper control of the testing equipment. Finally a heart beat was simulated with a expansion cycle at 2[Hz.] plus a waiting time of 0.5[s] which makes a total frequency of 1[Hz].

Data obtained from material testing was analysed and fitted to a mathematical model. Finite element models were also created for a coupled fluid-structure interaction where the pressure of fluid deforms the walls of the artery. Mathematical models where created to compare deformation forces form previous experimental studies to dynamic inertial forces.

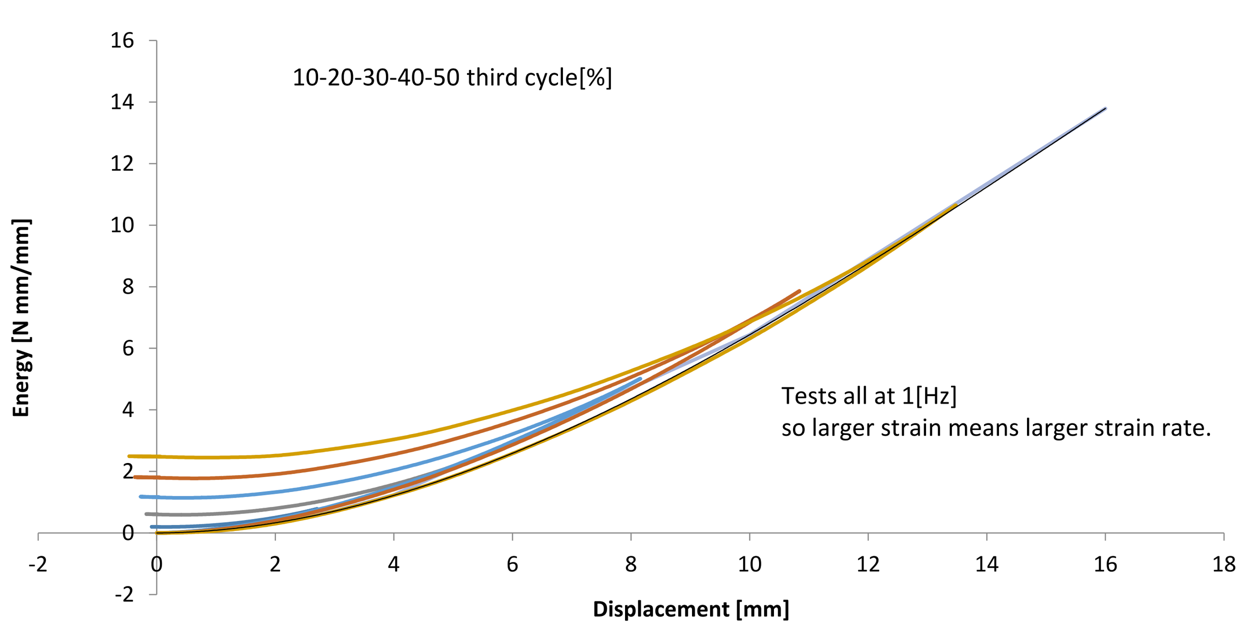




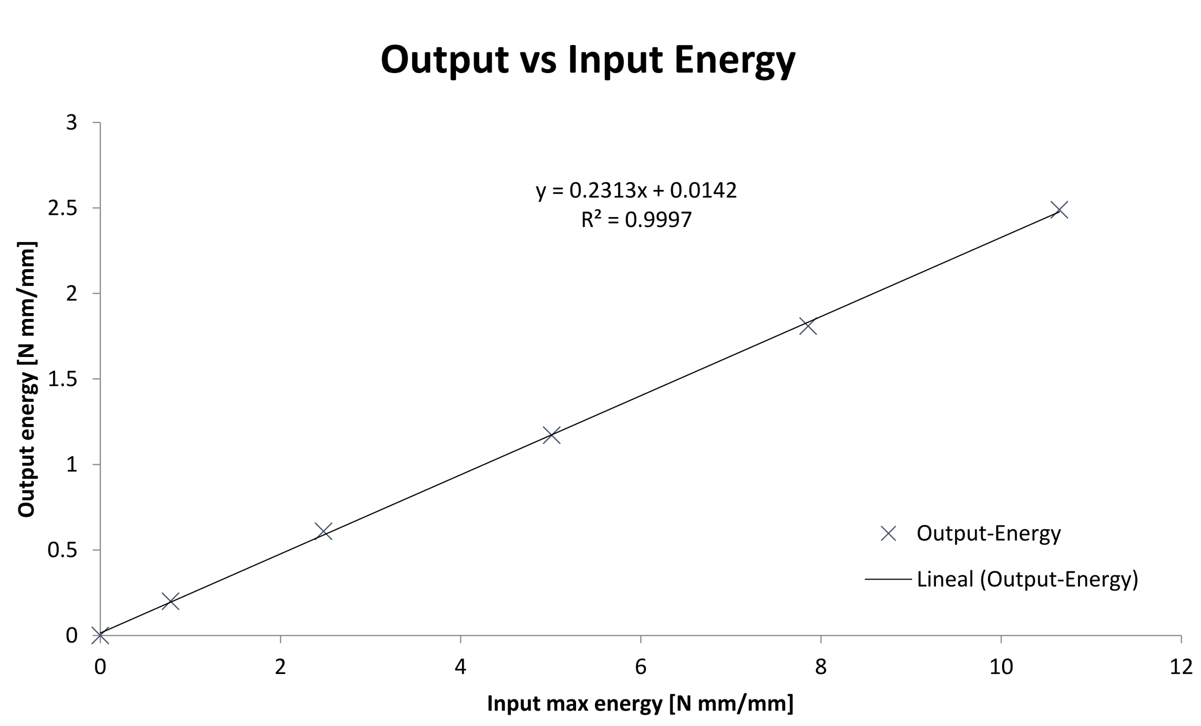
Material	PDMS	ePTFE
Thickness (mm)	2.4	0.5
Length (mm)	37.4	16.0
Width (mm)	10.0	9.5
Cross area (mm^2)	23.8	4.8

For the ePTFE tubes, a Maxwell material model was fit to the tests. A simplified model of the pressure wave was solved.

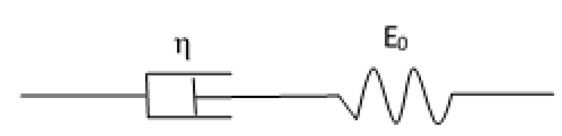
RESULTS



For the PDMS specimens, the energy along the oscillations was calculated by direct integration of the data. A linear correlation between input-energy and output-energy was found.

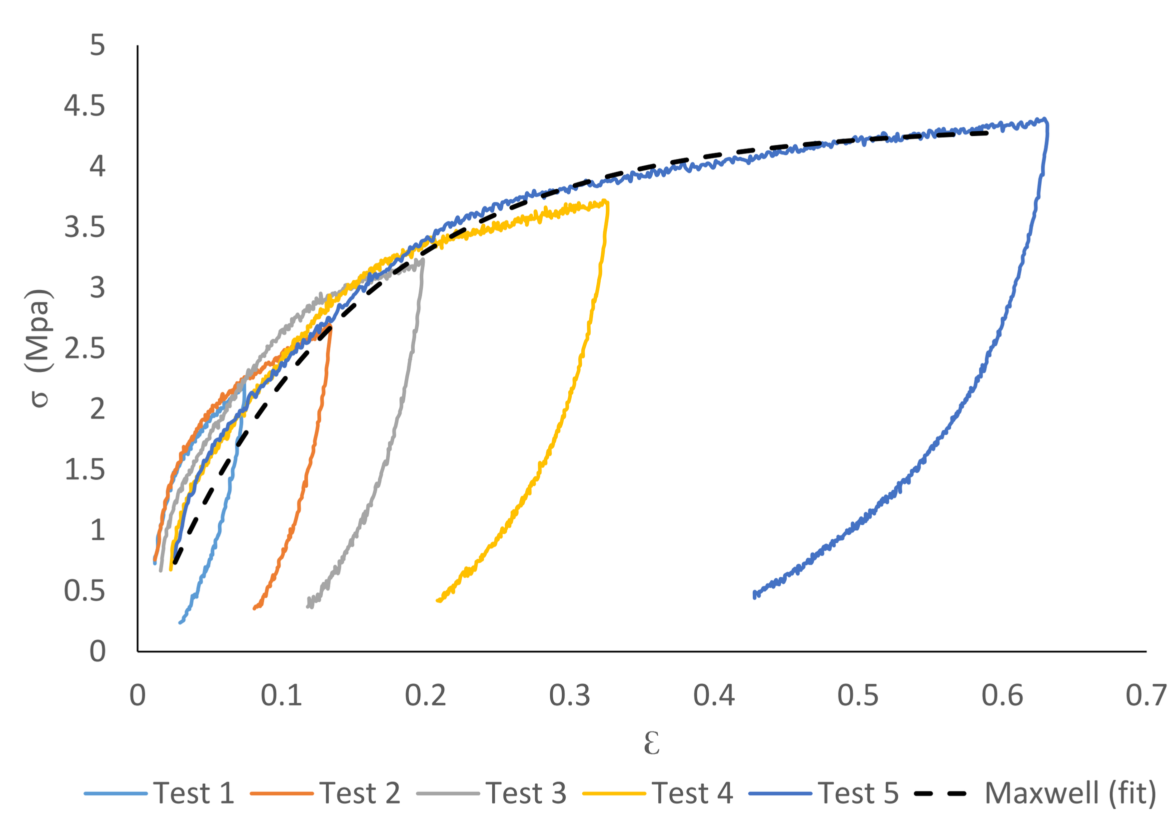


Fitting of the material model parameters to the ePTFE specimens.



Maxwell model for a viscoelastic material.

$$\varepsilon' = \frac{\sigma'}{E_0} + \frac{\sigma}{\eta}$$



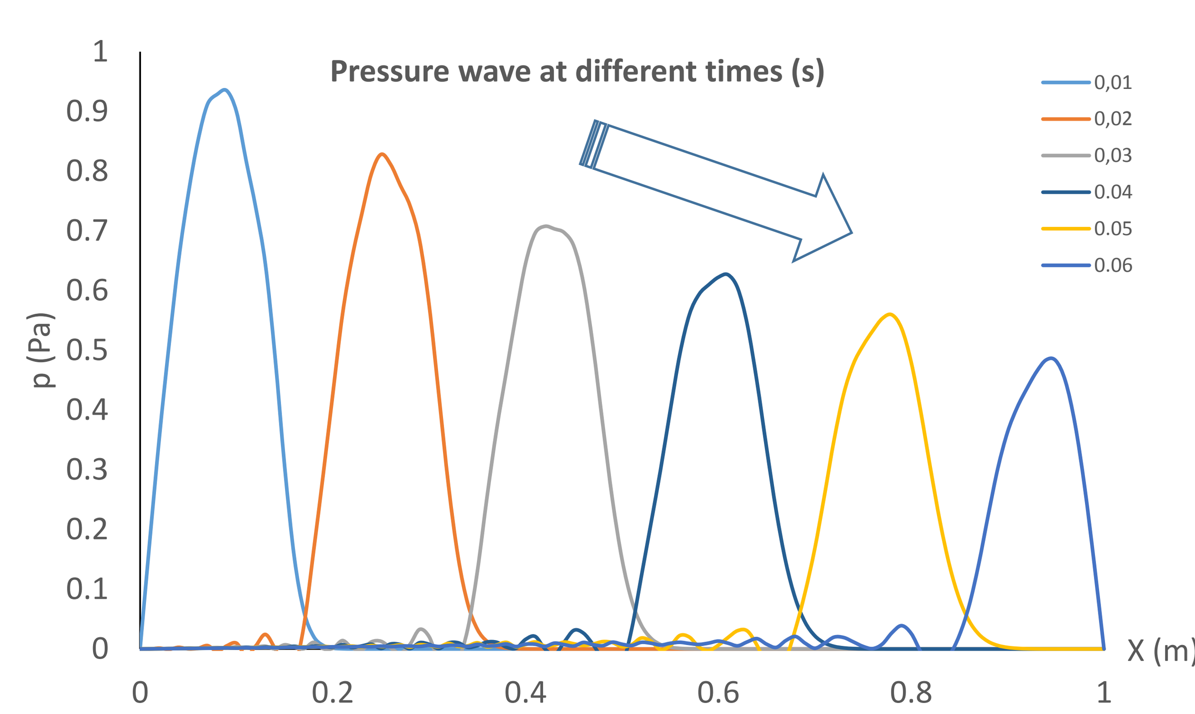
Pressure wave mathematical model (c is the wave velocity, and the time constant $\tau = \eta/E_0$).

$$\frac{\partial^2 p}{\partial t^2} + \frac{1}{\tau}\cdot\frac{\partial p}{\partial t} = c^2\frac{\partial^2 p}{\partial x^2}$$

$$c = \sqrt{\frac{E\cdot e}{2r\rho}}\ ;\ \tau = \frac{\eta}{E}$$

r [mm]	5
e [mm]	0.1
ρ [kg/m³]	1050
η [s]	682e06
E [MPa]	31

Numerical simulation of the pressure wave damping.



CONCLUSIONS

Material tests and mathematical models has been used in order to evaluate the pressure wave damping along blood vessels.

Pulse damping due to arterial expansion is produced mainly at aortic arteries where expansion reaches values of around 50%. Further studies and models are required with softer materials which are more similar to real arteries where the ratio of inertial force to deformation force is greater and scaling will not be allowed.

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