Heart beat pulse damping for medical materials

J. Aparicio, J. Martorell, G. Reyes, M. Balcells, A.A. Garcia-Granada, J. Menacho

IQS-Universitat Ramon Llull, Barcelona, Spain.

INTRODUCTION

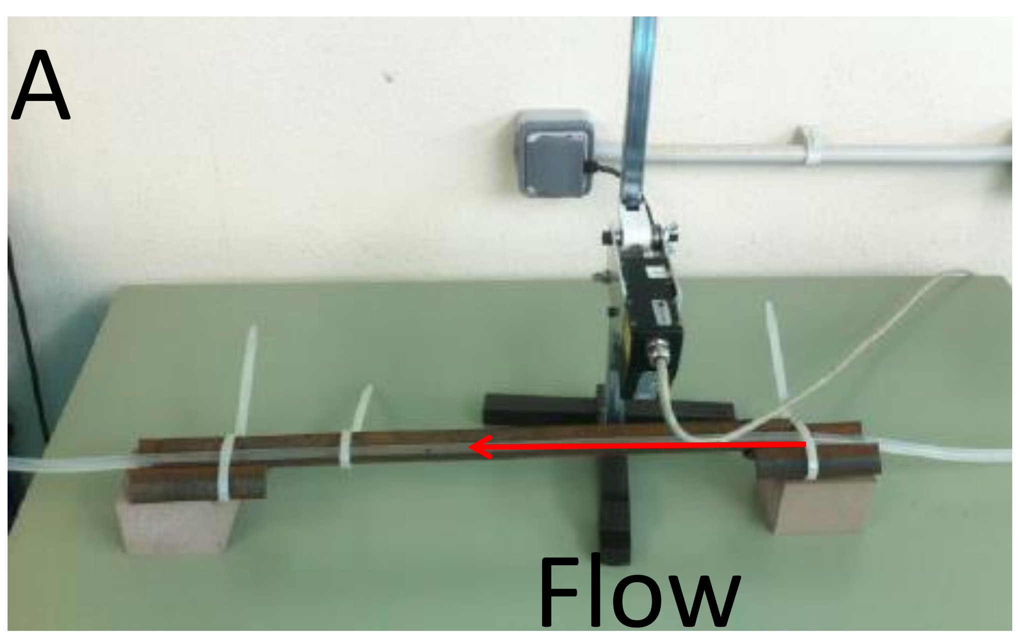
Recent evidence suggests a link between cardiovascular and neurodegenerative disease. The cause of cerebral micro-bleeds remains unresolved, though associations have been made with aortic stiffness, increased pulse wave velocity, and aging. Indeed, changes in pulsatile shear stress provoked by arterial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

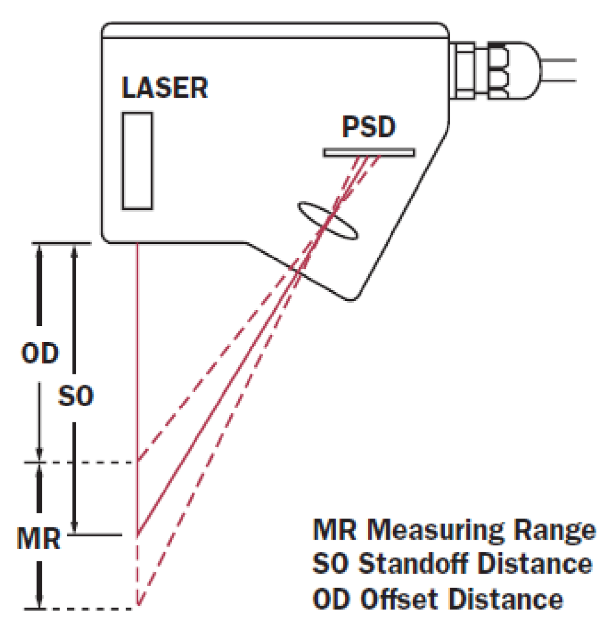
The aim of this research is to create a mathematical model showing how stiff arteries do not dump pulse wave. This model uses input data from experiments where arterial models are expanded in a controlled atmosphere.

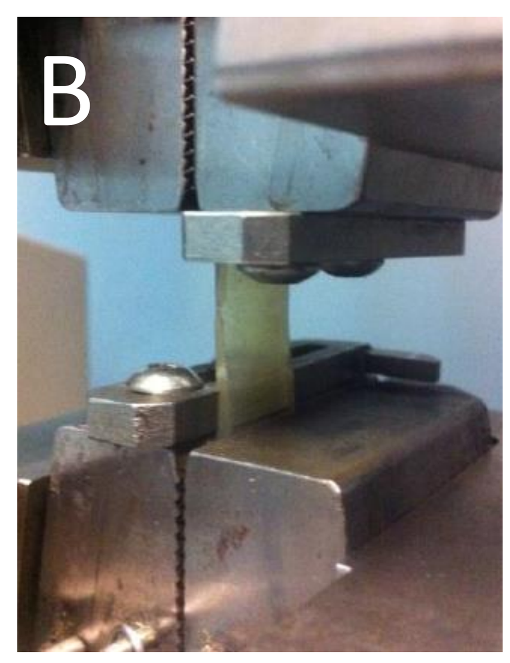
MATERIALS AND METHODS

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 analyzed 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 were created to compare deformation forces from previous experimental studies to dynamic inertial forces.







C	σ_{50} [MPa]	T thickness [mm]	ID Inner diameter [mm]	$P=\sigma_{50}$*t/(ID/2) [MPa]	$P=\sigma_{50}$*t/(ID/2) [mmHg]
PDMS1	0.5	2.4	9.5	1.2	1895
PDMS2	0.6	1	8	1.2	1125
ePTFE	2.5	0.5	10	0.25	1875
Artery*	0.1±0.09	0.49±0.13	5.1±0.8	0.02±0.019	157±142
3Dprint	0.05	0.5	5	0.02	75

Figure 1. Experimental setup.
A tube is connected to a peristaltic pump to induce pressure pulses that will expand the tube diameter. Laser equipment (A) is used to measure such tube expansion at high frequencies. Tubes made of several materials are sectioned and stretched in order to measure force-displacement during loading and unloading to check energy absorption (B). A table showing tubes stiffness or stress at 50% elongation, thickness, diameter and pressure to achieve 50% diameter expansion is given to compare experiments with real arteries (C) *Arterial data from C. Bussy, P. Boutouyrie, P. Lacolley, P. Challande, and S. Laurent, "Intrinsic stiffness of the carotid arterial wall material in essential hypertensives.," *Hypertension*, vol. 35, no. 5, pp. 1049–1054, 2000. Obviously there is a mismatch between interpretations of stiffness because pressure should be around 180-120=60 mmHg= 0.008 MPa. The idea is to create a tube material as close as possible to real arteries.

RESULTS AND DISCUSSION

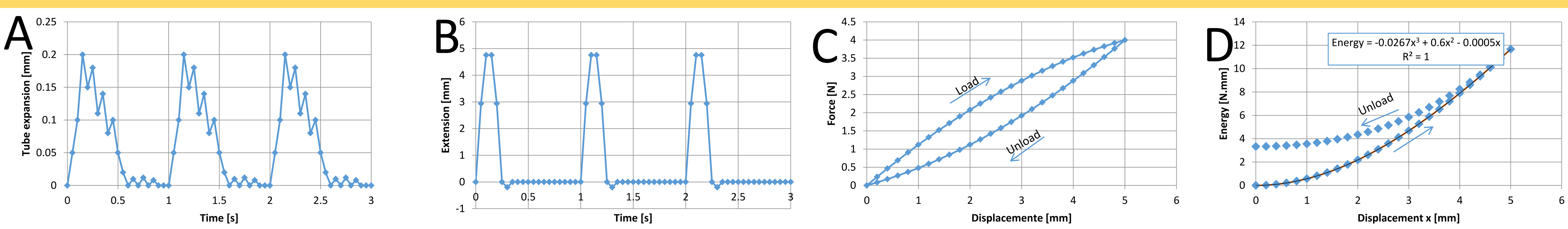


Figure 2. Experimental results.
Tube expansion is monitored vs. time (A) with laser equipment to feed numerical model with peristaltic pump pressure pulses. Load and unloading displacement vs. time (B) to obtain a force vs. displacement curve (C) were energy absorption is shown. Tests were carried out for several expansion ratios and a curve was fitted to experimental data (D). This curve fit shows input energy as a function of tube expansion. This fit will be used in simulations for each material. For lager expansions more energy was absorbed by the material.

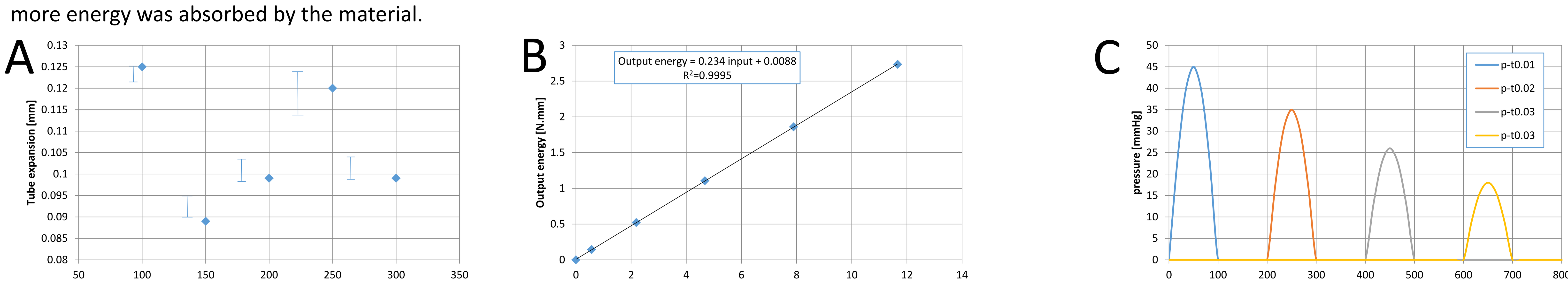


Figure 3. Energy absorption.
Pulsatile flow from peristaltic pump lead to small expansion of stiff tubes. Such expansion was measured at several position along the pipe expecting minor expansions to be found far from peristaltic pump (A). Energy absorption plotted as a function of input energy showed a good linear fit for experimental results (B). Such fit showed that for thick/stiff tubes expansion is small and also energy absorption is small . This curve fit of energy absorption was used to generate a mathematical model to predict pressure wave damping (C).

CONCLUSIONS

Material tests have been used in order to evaluate the energy decay of a pressure wave along tubes of different materials used for medical applications. Pulse damping due to material expansion is measured and correlated to the material characteristics. Initial experiments of pulsatile flow on tubes need to be carried out with weaker or thinner tubes to obtain a significant energy absorption.

CONTACT
A.A. García Granada: andres.garcia@iqs.edu
IQS - Via Augusta 390, E08017, Barcelona, Spain.

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