Comparison Between Theoretical and Experimental Reflection Coefficients in Flexible Tubes as a Function of the Mach Number

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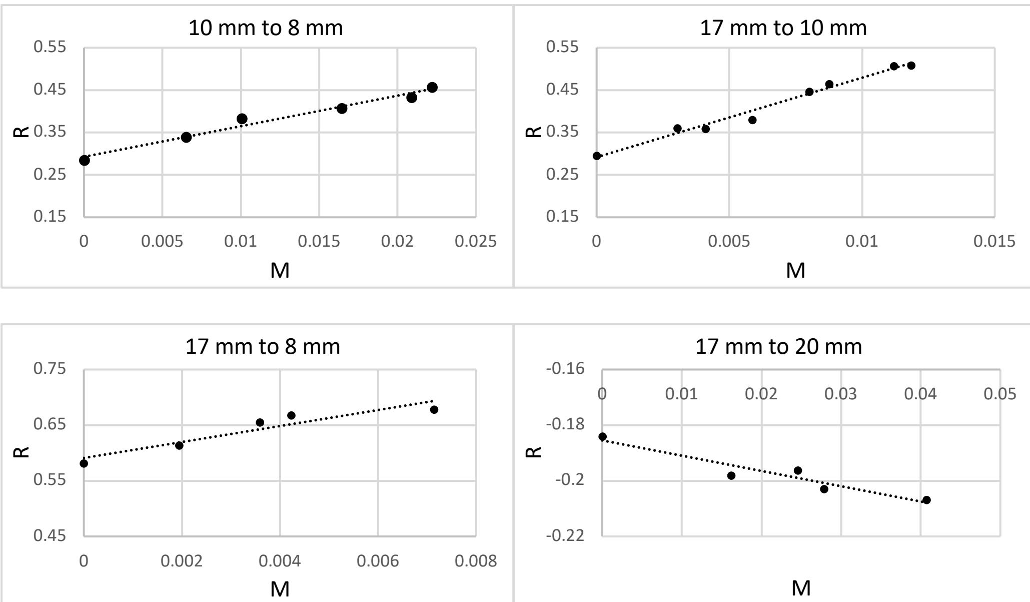
The standard formulation of Wave Intensity Analysis (WIA) assumes that the flow velocity (U) in the conduit is negligible with respect to the velocity of propagation of waves (c) in the system; U << c, where Mach number ($M = U/c$) is =~ 0. This assumption holds true in most regions of the arterial tree, however, in large conduit arteries U is relatively high due to ventricular contraction and c is relatively low due to the high compliance; thus M is significantly greater than 0. Therefore, the aim of this study is to identify experimentally the relationship between M and the reflection coefficient in vitro.

Combinations of flexible tubes, of 2 m in length with circular cross sectional area, isotropic and uniform material properties along their longitudinal axes of internal diameter of (8, 10, 17 and 20 mm) and wall thickness (1, 1.5, 2 mm) were used to present a mother connected to a daughter tube. An approximately semi-sinusoidal pulse was generated at the inlet of each tube using a syringe pump, first the waves speed was determined using the foot to foot and PU-loops methods in the condition of unperturbed velocity ($U_0=0$). The theoretical reflection coefficient (R_0) for M=0 has been calculated as $R_0 = (1-Y)/(1+Y)$, where $Y= 1/Z_0$; Z_0 is the characteristic impedance = ρ A/c, where ρ is the density and A is the cross sectional area. Then, superimposing steady flow using constant DC motor over the pulse waveform generated by a syringe pump, we recorded simultaneously pressure and velocity in the mother tube at a sampling rate of 500 Hz to identify the relationship between M and R. WIA was used to separate the pressure waveforms and the experimental reflection coefficients (R) at M>0 were determined as dP-/dP+, where dP+/- are the changes in pressure in the forward and backward directions.

In our experiments of pulsatile flow in long flexible tubes R increased significantly with small value of M (order of 10^{-2}). In the range of M=0 to 0.005, R increases by 4% to 36%. For low values of M a linear fitting of experimental data shows R^2=~0.99. Further, R changes significantly with the geometrical and mechanical features of the connected tubes. R is bounded between -1 and 1, so for higher values of M the linear fitting is expected not to be accurate. Further experiments with higher values of flow rate will clarify this point.



In pulsatile flow of flexible tubes where M is not negligible, the reflection coefficient provided by standard WIA is significantly altered by M. The reflection coefficient is not determined solely by geometrical and mechanical properties of flexible tubes but also by the relative value.