Influence of vessel tapering, compliance and blood velocity profiles on systemic arterial hemodynamics

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Background

A robust mathematical model is presented to compute pressure, flow and wall shear stress (WSS) distributions over the systemic arterial tree. Wave propagation in the large vessels is modeled through 1D balances of mass and momentum while contributions of the peripheral circulation are lumped into 0D windkessel elements.

Aim

To assess the influence of vessel tapering, velocity profiles and pressure-dependency of area and compliance, on systemic arterial pressure, flow and WSS waveforms.

Methods

Simulations were performed with the flat, parabolic, approximate or Womersley velocity profiles, with pressure-dependent or constant area and compliance and with convective acceleration due to tapering included or excluded. Deviations from a reference simulation were quantified by the relative difference (RD):

\[
RD = 100\% \cdot \sqrt{\frac{\sum_{m=1}^{W} \left(x(t_{m}) - x_{ref}(t_{m})\right)^2}{\sum_{m=1}^{W} x_{ref}^2(t_{m})}}, \quad x = \{p, q, \tau_w\}
\]

Results

Figure 2. RDs computed at four different locations in the arterial tree as depicted in the right top panel of figure 1. The reference model includes convective acceleration, approximated velocity profiles and pressure-dependence of area and compliance.

Conclusions

When estimating arterial pressure, flow and wall shear stress waveforms in the arterial tree:

- assuming a flat or parabolic velocity profile significantly affects the estimated values (RD>10% for wall shear stress), while differences between the more realistic Womersley and approximated velocity profiles are limited;
- pressure-dependency of vessel compliance should be taken into account;
- for vessels in the arm, convective acceleration has a negligible effect (flow and wall shear stress, maximum RD<10%).

References


Figure 1. Pressure, flow and WSS waveforms in the systemic arterial tree were simulated using 1D wave propagation equations (top left) complemented by assumed velocity profiles (middle left, for brachial artery) and pressure-dependency of vessel area and compliance (bottom left). Peripheral vasculature is modeled by 0D windkessel models (middle right). Aortic inflow is prescribed (bottom right). The arterial tree (top right) is adopted from [3].