Numerical investigation of wall pressure fluctuations downstream of ideal and realistic stenosed vessel models

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Cardiovascular diseases, the most common of which is atherosclerosis, are the leading global cause of death. Atherosclerosis leads to a plaque built up inside an artery, narrowing it down and forming a stenosis. It may lead to coronary artery disease, stroke or peripheral artery occlusive disease, depending on the location of the lesion. The flow turning into turbulent regime after passing the stenotic obstruction leads to pressure fluctuations at the arterial wall. The generated sound is transmitted through the surrounding tissue and reaches the skin. This acoustic radiation may give important information about the stenotic region as Seo et al. [1, 2] stated.

It is shown by Özden et al. [3] that eccentricity of the stenosis is the only parameter causing a considerable change in acoustic radiation magnitude for idealized vessel and stenosis shapes. In this study, the effect of using real and ideal stenosed vessel models on the generated acoustic radiation is investigated using numerical simulations. The idealized vessel-like model with an eccentric elliptical stenosis and a real vessel model with a realistic stenosis shape inspired by the MR image of a stenosis are given in Fig. 1. Inlet diameters are 6.4 mm and 7.2 mm for ideal and realistic models, respectively. Both these models have a stenosis severity of 87%.

Figure 1: (a) Idealized model, (b, c) Realistic model, (d) location of the line on the vessel wall along which pressure is collected

Steady flow simulations at a Reynolds number of 1000 (based on average velocity and un-constricted vessel diameter) are performed with dynamic Smagorinsky LES turbulence model of OpenFOAM. After the mean wall pressures reach steady-state, time history of fluctuating pressure data is recorded on the vessel wall downstream of the stenosis exit and converted into acoustic pressures, which are investigated in terms of amplitude and frequency content. The pressure data collected on the line represented by red point in Fig. 1(c) is post-processed with a MATLAB code performing Hanning window filtering, followed by FFT to provide contour plots seen in Fig. 2. Acoustic pressure amplitudes are converted to logarithmic scale using

$$p(\mathrm{dB}) = 20\log_{10}\left(\frac{p(\mathrm{Pa})}{p(\mathrm{Ref})}\right) \tag{1}$$

where p(Pa) is the pressure amplitude calculated by the simulations in pascals, p(dB) is the acoustic pressure amplitude converted into decibels, and p(Ref) is the reference pressure taken as 1 Pa.

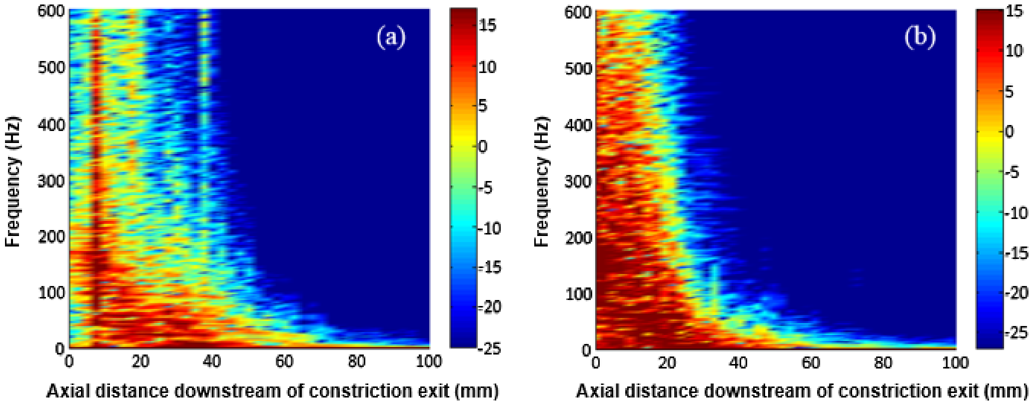

Figure 2: Acoustic pressure content for (a) ideal and (b) realistic stenosis models

It is seen from Fig. 2 that although spectral behavior shows similarities, both acoustic pressure levels and maximum excitation points are different. Maximum activity point of flow in realistic vessel is just at the exit of stenotic region whereas it is located at about 10 mm after the exit of the idealized stenosis geometry. Fig. 3 compares acoustic pressures at the maximum activity locations for ideal and realistic stenosis models. As seen, changing vessel and stenosis geometry from ideal to realistic leads to up to 10 fold increase in the acoustic pressure level.

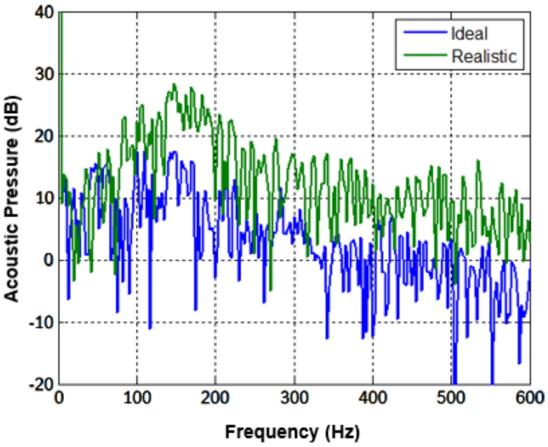

Figure 3: Frequency contents of the acoustic pressures for ideal and realistic stenosis models at maximum excitation locations.

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