Fluid-Structure Interaction Models of Aortic Coarctation and Repair: Lessons to be Learned for Hemodynamic Analysis

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Key Words: hemodynamics, fluid-structure interaction, aorta, wave reflections

Hemodynamic assessment involves processing of (central aortic) pressure and flow waveforms for the analysis of wave dynamics and wave reflections. It provides insight into the pathophysiology of the cardiovascular system and is thought to provide diagnostic and prognostic information. Arterial wave dynamics are, however, complex, with presence of both discrete and diffuse reflections, complicating the interpretation of data. In this study, we have constructed a series of fluid structure interaction (FSI) models based on a subject-specific model of a healthy aorta, progressively inducing more severe constriction and narrowing in the descending aorta to mimic aortic coarctation and repair scenarios (Figure 1). Inlet (inlet mass flow) and outlet boundary conditions (mass flow on arch side branches; 3-element windkessel model on distal aorta) were kept constant. The central aortic pressure and flow waveforms, following from the FSI simulations, were subsequently analysed using wave intensity and wave separation analysis. As expected, the combination of aortic constriction and stiffening had the largest impact on the aortic pressure waveform. When the pressure waveforms were decomposed into their forward and backward propagating components, not only the backward pressure wave increased in magnitude with increasing severity of the downstream intervention on the aorta, but also the forward pressure component increased in magnitude, despite the fact that neither the inflow, nor the proximal aorta had been modified. Wave intensity analysis revealed that re-reflection of the reflected waves at the aortic inlet is responsible for the observed increase in amplitude of the forward pressure wave. This effect is revealed when considering the wave intensity for the backward and forward waves separately (see Figure 2 for the case of a local stiffening of the descending aorta). These findings are important and might have important consequences for cardiovascular research, as routinely used procedures thought to quantify arterial wave reflections might be flawed.

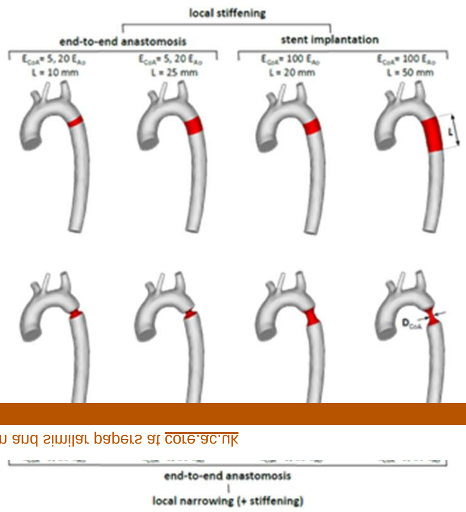

Figure 1 – Models of the aorta with (repaired) coarctation

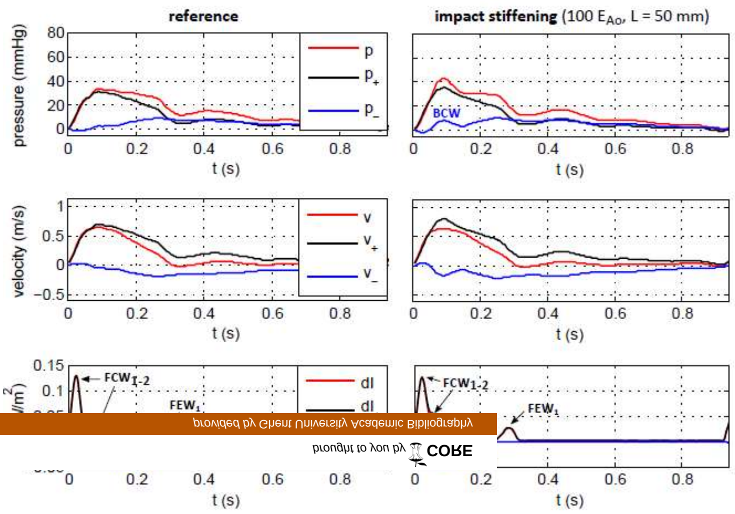

Figure 2 – decomposition of the pressure (top) and flow velocity (middle) waveforms in forward (+) and backward (-) components. Bottom: wave intensity demonstrating re-reflection of the initial reflection (BCW1) as a new forward wave (FCW2)