Fluid structure interaction in distensible blood vessels : a time-periodic coupling

Fluid Structure Interaction in distensible blood vessels: a time-periodic coupling

Bart Beulen, Marcel Rutten and Frans van de Vosse
Department of Biomedical Engineering, Eindhoven University of Technology

Introduction

Background: In clinical practice, ultrasound velocimetry is often used as a non-invasive method to determine flow through arteries. Generally the flow is derived by assessment of centerline velocity and assuming a certain velocity profile, e.g., a Poiseuille or Womersley profile. In-vivo, vessels can be slightly curved causing asymmetric velocity profiles. This results in inaccurate flow assessment.

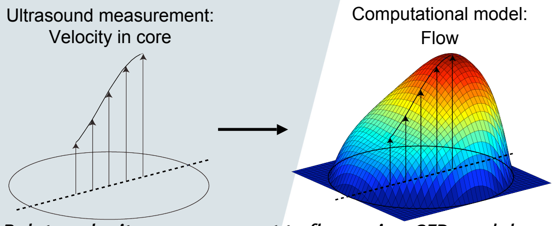

Figure 1 Relate velocity measurement to flow using CFD models

Computational Fluid Dynamics (CFD) can be a valuable tool to support ultrasound flow measurements and to relate the core velocity profile or centerline velocity measurements to volume flow (figure 1). However, for Fluid Structure Interaction (FSI) models for flow through long compliant vessels often problems arise due to coupling problems between solid and fluid problem.

Aim: Develop a coupling method which enables modeling of flow through long compliant vessels.

Model

Fluid and solid model are solved successively for each timestep since the pressure variations due to the flow are an order of magnitude smaller than the pressure wave traveling through the artery. A schematic overview of the coupling methods is presented in figure 2.

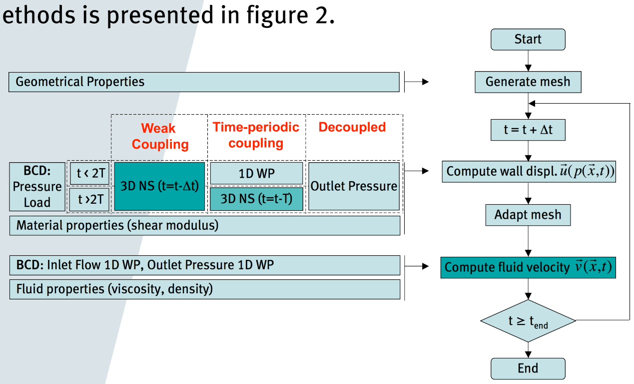

Figure 2 Overview of the coupling methods. 3D NS = 3D Navier Stokes, 1D WP = 1D Wave Propagation

In this study, a wave propagation model, based on an approximate velocity profile function[1], is used to provide the 3D FSI model with boundary conditions and an initial axial pressure distribution. Approximate solutions of subsequent time-periods are obtained using the pressure solution of previous time-period as an initial solution. This coupling method is referred to as the time-periodic coupling.

Results

The performance of the coupling methods is compared by performing FSI calculations on a vessel of increasing length-radius ratio, the results are presented in figure 3. The weakly-coupled method is only stable for L ≤ 10r.

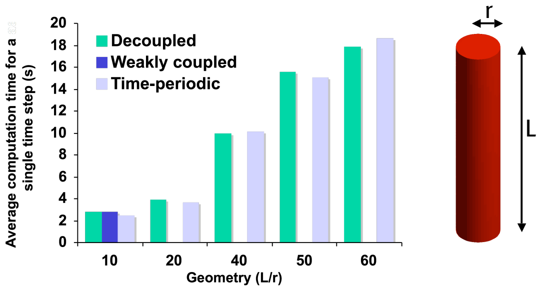

Figure 3 Performance overview of the various coupling methods

The time-periodic weakly coupled method is applied to a stylized carotid bifurcation geometry (figure 4).

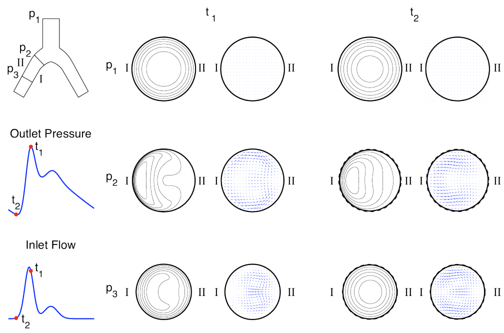

Figure 4 Results of the time-periodic FSI simulation performed on the carotid bifurcation. The flow field is visualized at three positions at peak systolic and end diastolic time.

Conclusions

The time-periodic weakly coupled method proves to have a better stability than weakly coupled methods based on timestep-wise coupling and is successfully applied to straight, curved and bifurcating geometries, resulting in accurate descriptions of flow fields and pressure distribution.

References:

[1] *Bessems et al. J. Fluid Mech. 2007*