Comparison of implicit and explicit FSI coupling strategies in cardiovascular system

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Introduction

There are two major strategies in FSI coupling techniques: implicit and explicit. The general difference between these methodologies is how many times the data is exchanged between the fluid and solid domains at each FSI time-step. In both coupling strategies, the pressure values coming from fluid domain calculations at each time-step are exported to the solid domain, and consequently, the solid domain is analyzed with these imported forces. In contrast to the explicit coupling, in the implicit approach the fluid and solid domain's data is exchanged several times until the convergence is achieved. Although this method may boost the numerical stabilization, it increases the computational cost due to the extra data exchanges. In cardiovascular simulations, depending on the analysis objectives, one may choose an explicit or implicit approach. In the current work, the advantage of an explicit coupling strategy is highlighted when simulation of pulsatile blood flow in elastic arteries is desired.

Materials and methods

In order to evaluate the possible differences between an explicit or implicit approach, an idealized curved aorta is modeled. A realistic pulsatile blood flow is imposed at inlet while an oscillatory pressure pulse is adopted as the outlet boundary condition. Applying different coupling strategies, the important parameters such as wall deformation, blood velocity and shear stresses exerted on inner wall are compared.

The solid model is constructed and analyzed with Abaqus[1] and the fluid domain is simulated by STAR-CCM+[2]. A Newtonian fluid is adopted for the blood while the constitutive material of the arterial walls is a hyperelastic Demiray model[3]. Abaqus Co-Simulation Engine (CSE) is the responsible of data exchange process between the fluid and solid domains.

Results and discussion

Starting from solid mechanic results, Figure 1 shows the comparison between wall deformations in explicit and implicit FSI methodologies, when the cardiac cycle is at its maximum flow timing, and consequently the maximum differences are expected. As it can be seen, the results coincide satisfactorily. Finally, the wall shear stress as the major parameter in formation of the arterial plaques and damages is evaluated and presented in Figure 2.

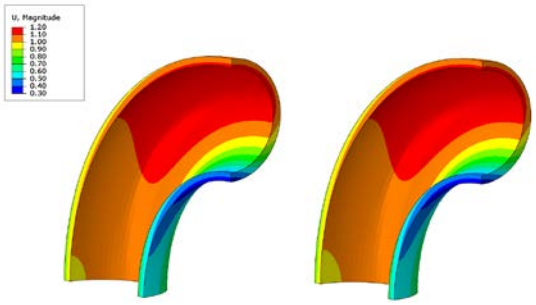

Fig. 1: Wall deformations (mm) at maximum velocity cardiac moment (0.16 sec); left: implicit, right: explicit.

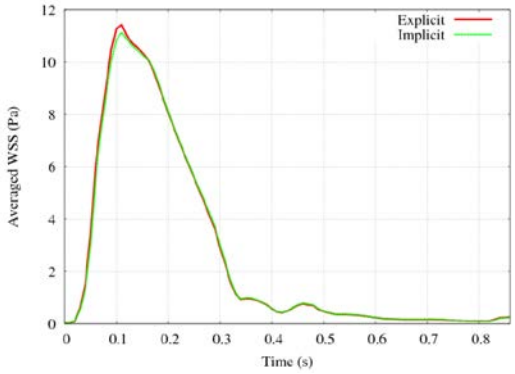

Fig. 2: Wall shear stress

Conclusion

The coupling strategy does not affect on the biofluid and biomechanical results, if the simulation objective is the simulation of pulsatile blood flow and oscillatory wall motions (pressure pulse transmission analysis is an example in which an implicit strategy is necessary). The major reason for the result independence to FSI coupling methodology is attributed to a relatively small change in flow and pressure values during one coupling time-step in a cardiac cycle. On the other hand, the principal issue which makes the two methods different is the computational cost, which it makes the explicit approach more interesting for cardiovascular biomechanics researchers.

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References

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