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M.Sc. Lars Radtke,
Hamburg

A partitioned solution approach for fluid-structure interaction problems in the arterial system

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The present work is concerned with the partitioned solution of the multifield problem arising from a hierarchical modeling approach to cardiovascular fluid-structure interaction. Different strategies to couple the participating field solvers are investigated in detail. This includes staggered and parallel coupling algorithms as well as different methods for convergence acceleration, spatial interpolation and temporal extrapolation of coupling quantities. In the developed modeling and simulation approach, a fully resolved model of a segment of the arterial network is coupled to reduced order models in order to account for the influence of the surrounding.

There is experimental evidence that hemodynamic quantities such as the wall shear stress promote the progression cardiovascular disease. Cardiovascular FSI simulations, that can predict these quantities, are therefore of great interest and can aid in surgical planning and optimization of anastomoses shapes and graft materials.

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Contents

List of medical terms

abdominal	Refers to the abdomen (stomach)
adventitia	Outermost layer of an arterial wall
anastomosis	Here, connection between bypass graft and artery
aorta	The largest artery in the body
atherosclerosis	Inflammatory disease in arteries
atrium	Smaller chambers of the heart
cardiovascular	Refers to the heart and the circulatory system
coronary	Refers to the heart
diastole	Phase of the cardiac cycle, where blood enters in the left ventricle
distal	Away from the body center, here downstream
dorsal	Refers to the back
endothelium	Layer of cells at the lumen boundary of an artery
erythrocytes	red blood cell
femoral	Refers to the thigh region
iliac	Refers to the intestine region
intima	Innermost layer of an arterial wall
intimal hyperplasia	Abnormal thickening of the intima
leucocytes	White blood cell
media	Middle layer of an arterial wall
proximal	Towards the body center, here upstream
pulmonary	Refers to the lungs
systole	Phase of the cardiac cycle, where blood leaves the left ventricle
thrombocytes	Platelets activating blood clotting
thrombosis	Formation of a blood clot
ventricle	Larger chambers of the heart

Abstract

The present work is concerned with the partitioned solution of the multifield problem arising from a hierarchical modeling approach to cardiovascular fluid-structure interaction. Different strategies to couple the participating field solvers are investigated in detail. This includes staggered and parallel coupling algorithms as well as different methods for convergence acceleration, spatial interpolation and temporal extrapolation of coupling quantities as well as convergence criteria. In the developed modeling and simulation approach, a fully resolved model of a segment of the arterial network is coupled to reduced order models in order to account for the influence of the surrounding. The resulting problem is solved using five specialized field solvers, namely a fluid and a structural solver for the three-dimensional fluid-structure interaction problem, a one-dimensional blood flow solver for the surrounding vessel network, a solver for different types of windkessel models used to obtain physiological boundary conditions at the distal ends of the one- and three-dimensional models, and a solver for an elastic foundation that describes the surrounding tissue. The applicability of the solution approach is demonstrated in terms of several exemplary applications including studies of idealized and patient specific end-to-side anastomoses of bypass grafts. They are known to be prone to the development of intimal hyperplasia, i.e. a thickening of the vessel wall that may lead to occlusions in the anastomosis region. There is experimental evidence that hemodynamic quantities such as the wall shear stress promote the progression of this secondary disease. Cardiovascular FSI simulation are therefore of great interest and can aid in surgical planning and optimization of anastomoses shapes and graft materials.