6982 We, 09:15-09:30 (P29)

Large-scale subject-specific simulations of blood flow in deformable arteries using a coupled-momentum formulation

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Application of fluid–structure interaction methods in simulation-based medical planning remains a formidable problem for large, realistic anatomic and physiologic models, since multiple surgical interventions need to be modeled, solved, analyzed, and compared in a clinically relevant time-frame (hours). We have developed a new method to simulate blood flow in three-dimensional deformable models of arteries based on a coupled-momentum formulation of the equations of the fluid and the solid domains [1]. We consider a strong coupling of the degrees-of-freedom of the fluid and the solid, and a linear membrane model (enhanced with transverse shear) for the vessel wall. The effect of the vessel wall boundary is added in a monolithic way to the fluid equations, resulting in a remarkably robust scheme. In this paper, we present the application of the method to different large-scale subject-specific models of the vasculature, considering physiologic levels of flow and pressure [2]. We discuss the potential of the method to incorporate important features such as variable vessel wall mechanical properties, and the effects of the surrounding tissue on the system (i.e., added mass, stiffness and damping) [3].

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5733 We, 09:30-09:45 (P29)

Quantitative analysis evaluation of flow characteristics in elastic artery with fluid–structure interaction model using real pulsatile pressure waveforms

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Endothelial cells lining a blood vessel are exposed to both wall shear stress of blood flow and circumferential strain of pulsating artery wall motion. These two forces and their interaction are believed to play a very important role in determining remodeling of the blood vessel and development of arterial disease. The transmission of pressure waves at finite velocity through the blood is the result of the energy exchange between the blood and the vessel walls, therefore the modeling of the time evolution of the arterial deformation or pulse propagation, is a fluid-interaction problem.

In this paper, a FSI model to simulate fluid–solid interaction on the blood vessel. An elastic incompressible material with large deformation was considered for arterial wall and momentum and continuity equations of elastodynamics have been solved. The specified boundary conditions for the Navier–Stokes equations are real pulsatile pressure waveform of brachial artery [2] at inflow and outflow to the given pulse wave form of a cardiac cycle. The FSI algorithm has been evaluated with comparing the results obtained from FSI model for high elastic modulus and solid model with no FSI algorithm. The significant increasing in time dependent wall shear stress with increasing elastic modulus of vessel wall were obtained. At the same pressure gradient and different stiffness of vessel wall different flow rate was obtained.

The results have shown this model estimates flow rate more precisely in high pressure values than theoretical model [3]. It can be concluded that the measuring of pressure wave and using it as a boundary condition is non-invasive and more suitable to study the blood vessel characteristics.

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T2.2 Respiratory Mechanics FSI – Aerodynamics and Vibrations

4487 Tu, 14:00-14:15 (P23)

Alveolar flow simulations during rhythmical breathing motion in reconstructed XTM acinar airspaces

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Respiratory airflows in the pulmonary acinus are characterized by low Reynolds numbers (typically $Re < 1$) in airways marked by the presence of alveoli. Due to the sub-millimeter dimensions and accessibility of the region, acinar flows remain usually difficult to assess, and to date, simulations have been largely based on geometrical models derived from anatomical descriptions of the acinus [1,2]. In the present novel investigation, we perform computational fluid dynamics (CFD) simulations in real alveolar airspaces obtained from X-ray tomographic microscopy (XTM) images [3]. High resolution (1.4 1.4 1.4 μm voxels) three-dimensional alveolar wall structures and airspaces are extracted and reconstructed from XTM data obtained from pulmonary acinar tissue of a 10 days old mouse. An unstructured mesh is then generated for the chosen complex geometries (e.g. terminal alveolar spaces). Transient respiratory flows are solved for rhythmic expansion and contraction motion of the alveolar space, modeled using self-similar moving wall boundary conditions to simulate realistic breathing conditions [4]. The resulting alveolar flow patterns may be complex and are governed by the fluid–structure interactions existing at the alveolar walls, through the implementation of no-slip boundary conditions. We further investigate the fate of inhaled particles and their deposition within alveolar spaces using particle tracking methods. The simulations obtained give further insight on the true nature of micro-flows present in the pulmonary acinus. Furthermore, it is our belief that the present simulations are the first to date to use real acinar geometries with such high resolution.

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5944 Tu, 14:15-14:30 (P23)

Fluid–structure interaction in obstructive sleep apnea: Validation of numerical simulations using in-vitro measurements

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Clinical Context: An obstructive apnea consists in brief cessation of respiratory airflow, caused by soft tissue collapsus within the upper airway [1]. Numerical simulations of the involved fluid–structure interaction are of interest for clinical applications. In this context, simulations must be experimentally validated.

Material and Methods: *Numerical simulations:* Several simplifications were considered to limit the computation time regarding the aimed application in clinical practice. Linear elasticity and small perturbations assumption were chosen for the soft tissue. An asymptotic simplification of the full Navier–Stokes equations – Reduced Navier–Stokes/Prandtl – was used for the respiratory airflow [2]. The complete set of equations is solved numerically [3].

Experimental validation: Systematic comparisons between simulations and measurements performed on an in-vitro replica of the tongue and of the oropharynx were carried out. The setup consists in a deformable tongue made of latex, connected to a rigid pipe in which the airflow circulates [3]. Pressure distribution was measured while the deformation was quantified using a digital camera. Computer simulations were performed and confronted to the measurements.

Results and Discussion: The results of the comparisons are:

- partial obstruction (hypopnea) is observed;
- the prediction accuracy is within 30% for the pressure distribution, and within 10% for the deformation.

This study tends to prove the ability of our method to predict accurately a fluid–structure interaction, in conditions close to those of an apneic episode. In particular, simplified assumptions revealed to be sufficient and led to a dramatic speed up of the simulations.

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