11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

# Tracer transport in human arteries affects MRI-based perfusion quantification

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**Key Words:** *Perfusion Quantification, Magnetic Resonance Imaging, Contrast Agent Transport, Outlet Boundary Conditions.*

**INTRODUCTION –** Measurement of tissue perfusion may be used for diagnosis of conditions such as coronary artery disease or stroke [1]. Quantitative first-pass magnetic resonance imaging (MRI) is a promising technique to directly measure tissue perfusion parameters such as myocardial blood flow (MBF) or cerebral blood flow (CBF) [2,3]. Precise quantification requires, however, accurate knowledge of the arterial input function (AIF), i.e. the concentration of an injected contrast agent (CA) entering the tissue of interest. Between the point of AIF measurement and the tissue of interest, however, CA dispersion may occur. In this contribution, we employed CFD simulations to investigate the dispersion of CA in realistic human artery models and its influence on quantitative MRI perfusion measurements.

**METHODS** - Geometric models of the left circumflex coronary artery (LCX) and of the arterial tree following the left middle cerebral artery (MCA) were created based on a computed tomography scan of a corrosion cast specimen and on an MRI angiography scan of a volunteer, respectively, using the open-source software vascular modeling toolkit (Fig. 1). Hexahedral meshes containing 560,414 elements (LCX) and 2,851,804 elements (MCA) were created using commercial software (ICEM CFD 14, Ansys, Darmstadt, Germany). Blood flow and CA transport were then simulated using the open-source software OpenFOAM (OpenFOAM 2.1.0, OpenCFD Ltd., ESI Group, Bracknell, United Kingdom) on a High Performance Cluster (Elwetritsch, RHRK, TU Kaiserslautern, Germany) using 32 processors. Realistic velocity patterns were assigned at the inlets of the 3D models, and the inflow of CA was described by a gamma-variate function. Several outlet boundary condition (BC) models were implemented in the OpenFOAM framework and compared in the LCX model: Constant pressure at all outlets [4], resistance BC [4], Olufsen's structured tree model [5], and a radius-dependent flow split [6]. MBF quantification

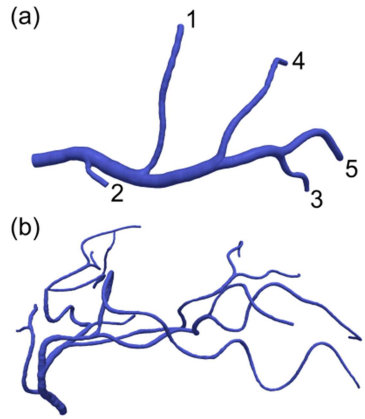


Fig. 1. (a) The 3D model of the LCX artery and (b) of the arterial tree following the MCA artery.

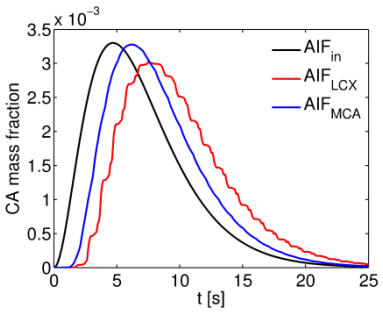


Fig. 2. CA mass fraction curves at the inlet, at outlet 3 of the LCX model using the constant pressure BC, and at outlet 11 of the MCA model.

was performed using the tracer-kinetic model MMID4 [7], and truncated singular value decomposition was applied to calculate CBF [8].

**RESULTS –** CA dispersion was for all outlets much larger for the LCX model than for the MCA model, as shown exemplarily in Fig. 2. MBF errors that arise if CA dispersion is neglected for the LCX model were considerable and varied substantially between the different outlets (range -31.1% to -5.4%). All BC models except the constant pressure BC yielded very similar levels of MBF underestimation (Fig. 3). Due to the much smaller dispersion in the MCA model, only mild CBF underestimation was found (range -0.3% to -7.9%).

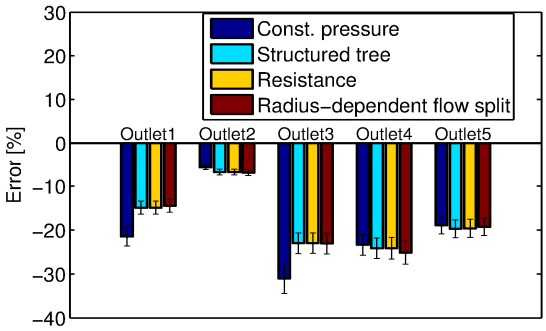

Fig. 3. MBF errors in the LCX model that arise if CA dispersion is neglected for all outlets and all employed outlet BCs.

**DISCUSSION –** Our results indicate that dispersion of an injected CA leads to a systematic underestimation of MBF/CBF values in MRI-based perfusion quantification. The much larger errors in the LCX model are likely to be caused by smaller blood flow velocities in the coronary arteries. Considering the relatively small CBF understimation due to CA dispersion, more distal locations for measuring the AIF such as the internal carotid arteries may be considered. Future studies should include a simulation of CA transport in the entire cerebral arterial tree to evaluate different AIF measurement locations, as well as the influence of vascular occlusions.

**ACKNOWLEDGMENTS** - This work was supported by a Carl Zeiss Foundation Dissertation Fellowship for Karsten Sommer and by the Max Planck Graduate Center with the Johannes Gutenberg-Universität Mainz (MPGC).

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