Non-cartesian flow MRI for determining highly accurate velocity vector fields and Reynolds stress tensors

Jeanette Schulz-Menger, Sebastian Schmitter, Tobias Schäffter

Application Area: Cardiovascular, **Modality:** MRI

Background: Phase-contrast (PC) based flow MRI is a unique imaging technique that allows a non-invasive measurement of the blood's velocity vector field e.g. in the human heart or aorta (Figure 1a). This technique also becomes increasingly important for studying in detail the hemodynamics in 3D printed replica of vessels of diseased patients, such as a stenosed aorta (Figure 1b). In addition to the velocity vector field and derived parameters like the wall-shear stress (WSS), it has been shown that also the turbulent component can be assessed using MRI methods, which allows calculating the turbulent kinetic energy and the Reynolds stress tensor. However, conventional cartesian-based flow MRI acquisition techniques are biased by the finite duration of the velocity and spatial encoding process, which yields displaced and biased results (Figure 1b), particularly when aiming for high resolution (1). While a cartesian-based, bias-free acquisition exists (3) this technique requires several hours or up to days which limits its use. Non-cartesian acquisitions in contrast are less prone to such artifacts and can achieve s much higher accuracy as conventional methods, even at high spatial resolution. Investigating this effect and its impact on the flow vector field and derived parameters is the aim of this project.

Hypothesis: Non-cartesian PC-MRI flow acquisitions allow an improved accuracy and precision for correctly quantifying the velocity vector field, the Reynolds stress tensor and for calculating the pressure loss in patients with aortic stenosis.

Methods: In this project we will develop non-cartesian-based PC flow MRI sequences based on radial and spiral trajectories. Using a magnetic field camera, the gradient trajectories will be measured, and this information will be utilized during the image/velocity reconstruction process. Based on the resulting acquisition, the precision and accuracy of the resulting vector field as well as derived parameters such as WSS, turbulent energy and Reynolds stress tensor will be analyzed and compared to classical and bias-free methods. The clinical benefit of this novel technique will be investigated first in healthy subjects and subsequently in patients with aortic stenosis.

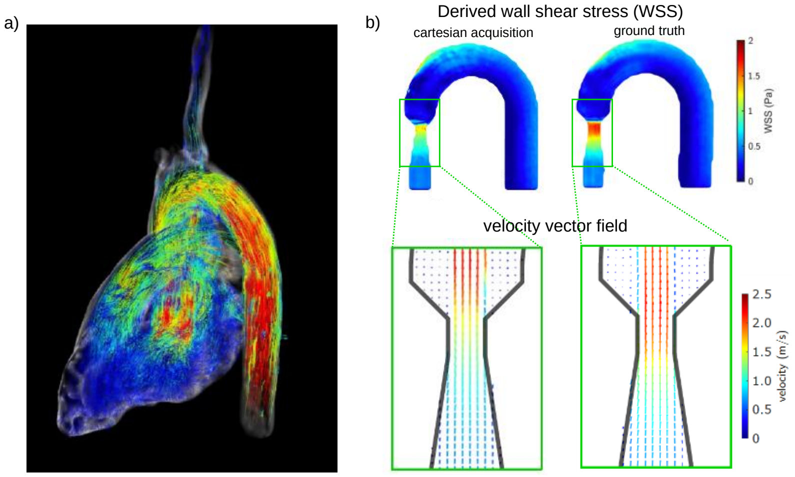

***Figure 1**: a) Velocity vector field in the human heart and aorta during systole visualized by streamlines. b) Derived WSS values (top) and the underlying flow field (bottom) for a cartesian acquisition (1) and a slow but accurate reference acquisition (2).*

Collaborations: The project will be performed in close collaboration between Prof. Schulz-Menger and her group at Charité hospital and Dr. Schmitter and his group at PTB. The students will join our joint project meetings as well as our regular joint group meetings for discussions, presentations, and feedback. Furthermore, the project will be strongly linked to the group of Dr. Kolbitsch at PTB, particularly concerning the image reconstruction.

Impact: The work will enable the highly accurate measurement of the velocity vector field and derived parameters, which allows future investigations and promotes understanding of hemodynamics in various cardiovascular diseases.

References:

1. Schmidt S, Flassbeck S, Schmelter S, Schmeyer E, Ladd ME, Schmitter S. “The impact of 4D flow displacement artifacts on wall shear stress estimation.” *Magn Reson Med. 2021 Jun;85(6):3154-3168. doi: 10.1002/mrm.28641.*
2. Bruschewski M, Kolkmann H, John K, Grundmann S. " Phase-contrast single-point imaging with synchronized encoding: a more reliable technique for in vitro flow quantification *", Magn Reson Med. 2019 May;81(5):2937-2946. doi: 10.1002/mrm.27604. Epub 2018 Nov 13.*
3. Kadbi M, Negahdar M, Cha JW, et al. "4D UTE flow: a phase-contrast MRI technique for assessment and visualization of stenotic flows." *Magn Reson Med. 2015;73(3):939-950.*

Please contact Sebastian Schmitter (sebastian.schmitter@ptb.de) for any further questions on this project.