Optimal Quantitative Flow Analysis of CINE Phase Contrast 2D or 3D MR data

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Time-resolved (CINE) phase contrast (PC) MRI permits the assessment of blood flow within entire 3D vascular structures [1, 2]. The resulting high-dimensional datasets (3 spatial dimensions, 3 velocity directions, and time) require new visualization and quantification methods to derive reliable clinical parameters. In this context, an advanced flow quantification tool was developed based on detailed planar analysis of measured three-directional velocity fields [2]. State of the art interpolation and numerical methods were employed to provide optimal quantitative assessment of flow and derived vessel wall parameters such as wall shear stress (WSS). Initial results in volunteer and patient studies of the thoracic aorta illustrate the potential of such parameters to characterize the link between disturbed blood flow and mechanical properties of the vessel wall.

Optimized planar flow and vessel wall quantification was successfully applied to synthetic data, a MR flow phantom and in human studies. For each dataset, several flow parameters of interest were derived: geometrical information (time-resolved: area, perimeter, equivalent diameter), flow (time-resolved flow, flow acceleration, flow per cardiac cycle, regurgitant flow ratio, resistance index, pulsatility index), Reynold number, kinetic energy and wall shear stress (vectorial WSS and *oscillatory shear index* (OSI)).

Quantification of CINE PC-MRI data is a challenging task because of the limited spatio-temporal resolution, SNR and the difficulty to accurately segment vessel lumen. Most approaches until now have consisted in using either a restrictive flow model (e.g. paraboloid) or numerical flow simulations. However, due to the limitations of those methods (restrictive model, time consuming flow simulations and difficulty to simulate flexible walls), clinical applications have been limited. In contrast, the method presented here aims at a direct quantification of flow parameters by using Green’s theorem and cubic B-spline interpolation with their essential finite difference property to provide optimal quantification. Simple parameters such as the flow volume can be accurately quantified even for low resolution data while local flow parameters such as WSS are more limited by the spatio-temporal resolution and noisiness of MR data. Nevertheless, the spatial repartition of velocity that MR offers is translated into the derived WSS and initial in vivo results on volunteers and patients are promising. Although the estimated WSS is limited in its absolute accuracy, WSS patterns may have the potential to analyze the impact of altered hemodynamics on the vessel wall.

$$A = \left| \oint_{\partial D} \left(x(t)\dot{y}(t) - y(t)\dot{x}(t) \right) dt \right| \quad (1)$$

$$|Flow| = \left| \int_{\partial D} P_{Vz}^{y}(t)\dot{x}(t)dt \right| \quad (2)$$

$$P_{Vz}^{y}(x,y) = \int_{-\infty}^{y} Vz(x,\tau)d\tau \quad (3)$$

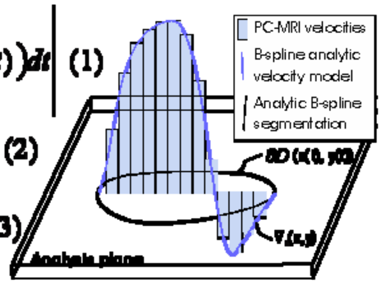

Figure 1 Area and flow using B-spline interpolation and Green's theorem

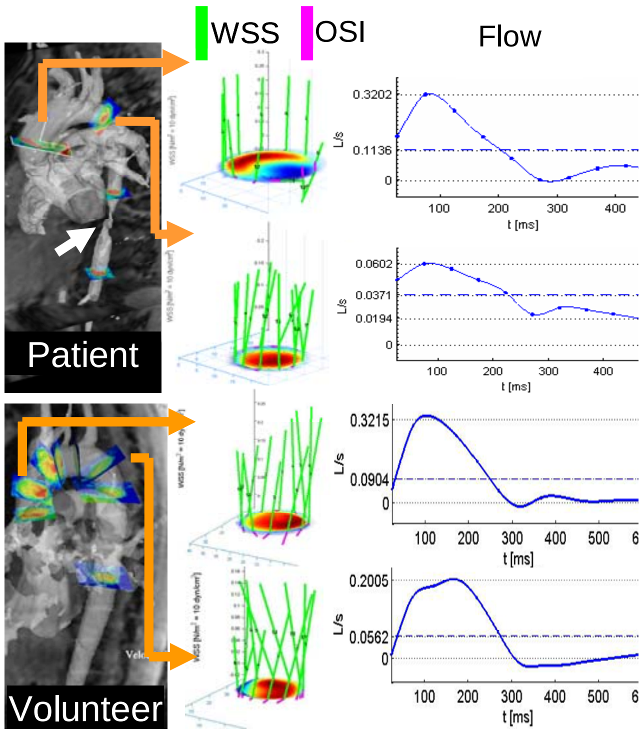

Figure 2 WSS analysis and flow quantification: The placement of retrospectively defined 2D analysis planes transecting the thoracic aorta (ascending aorta (AAo) and proximal descending aorta (DAo)) allowed for the quantitative evaluation of mean WSS, normalized OSI and flow in a volunteer (bottom) and a patient (top) with coarctation in the DAo (white arrow). Altered hemodynamics in the patient DAo led to vortex formation and locally retrograde flow in the AAo that eventually induced low and oscillating WSS along the inner wall compared to findings in the normal volunteer.

[1] Markl M, Harloff A, Bley TA, Zaitsev M, Jung B, Weigang E, Langer M, Hennig J, Frydrychowicz A. Time-resolved 3D MR velocity mapping at 3T: Improved navigator-gated assessment of vascular anatomy and blood flow.
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[2] A.F. Stalder, A. Frydrychowicz, C. Canstein, J. Hennig, M. Markl
Quantitative Planar Analysis of Flow Sensitive 3D CINE MRI
Proc. ISMRM Workshop on Flow and Motion, NYC, 2006