MRI assessment of the arterio-venous fistula

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Introduction: The autogenous arterio-venous fistula (AVF) is the recommended vascular access for patients undergoing permanent dialysis therapy. It is created during a surgical procedure by connecting an artery to a vein where the expected outcome is a mature fistula, capable of sustaining a minimum blood flow of 400ml/min. However, a high number of created fistulas fail to develop sufficiently to allow dialysis (30 – 50%) or, in time, fail to sustain adequate flow [1, 2]. Local hemodynamic factors, such as wall shear stress (WSS), play an important role in arterial remodeling and atherosclerotic disease [3], and could be one of the key factors in explaining fistula failure. **The aim** of the current work was to develop an MRI protocol for the assessment of the hemodynamic parameters of AVFs without using Gd contrast as these patients are all in renal failure.

Methods: The imaging protocol, performed at 1.5T (Siemens Avanto, Erlangen Germany), consisted of a 2D time of flight (TOF) sequence for anastomosis localization, followed by a higher resolution 3D TOF acquisition (TE/TR = ms, voxel size = 0.25×0.25×0.6mm). Through-plane blood flow velocities in the feeding artery and draining vein were measured 3cm above the anastomosis, perpendicular to each vessel with a 2D phase contrast (PC) sequence (VENC = 150 cm/s, voxel size = 0.78×0.78×5mm). Velocity maps measured with PC-MRI were corrected for background phase errors using a 2nd order polynomial surface fit of the static tissue of the arm. Total duration of the scan did not exceed 40 minutes.
For detailed analysis of velocity fields and wall shear stress distributions, computational fluid dynamics (CFD) simulations were performed using a finite volume solver, Fluent (Fluent Inc). The simulations were carried out on patient-specific geometries obtained by manual segmentation of the 3D TOF data. Boundary conditions required for the numerical solution were obtained from PC-MRI.

Results: 7 patients were evaluated. These individuals had fistulas at different stages of development. The angiograms had sufficient image quality to permit vessel segmentation although signal diminution was noted in venous structures as is expected for 3D TOF-MRA. Careful attention was required in setting VENC values because of the substantial increase in flow velocities that resulted from fistula creation. Baseline MRI performed on patients prior to surgery (N=3), showed mean blood flow in the brachial artery of 79±7 ml/min at the elbow region. Fistula placement lead to a 9 fold increase in arterial mean blood flow rate (726±217ml/min) within 5 days (N=3); these values showed a linear dependence on the lumen area of the draining vein.
At one month post surgery the arterial mean blood flow rate had increased to 1037 ml/min (N=1). An increase in the luminal area of 15% in the artery and 37% in the vein was also observed.
A comparison of the flow fields and WSS distributions obtained for one of the patients after 5 and 35 days following the surgery are shown in Fig.1. The streamlines show swirling flow in the draining vein at day 5 post surgery that changed into more unidirectional flow at the later point. Sites of recirculating flow were identified in the vein segment, distal to a sharp corner region at day 5, and distal to the anastomosis at day 35. At both imaging points, stagnation zones were observed in the artery, downstream of the anastomosis. The adaptation of the venous segment resulted in reduction of area with elevated WSS by day 35 post surgery.

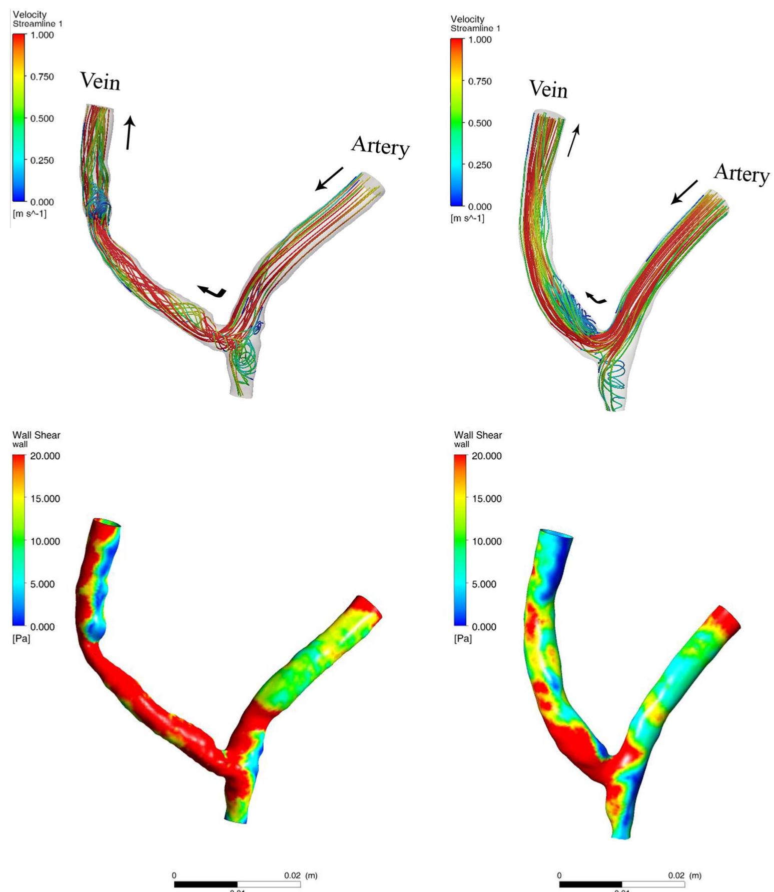

Figure1. Flow patterns (top) and WSS distribution (bottom) in a patient specific geometry obtained 5 (left) and 35 days (right) after fistula creation.

Conclusion: The initial results presented here show good promise in applying this protocol to a longitudinal study of AVF progression. MRI is the most suitable modality for this application, as it provides an angiographic map, velocity measurements and potentially, information on the vessel wall morphology, in one imaging session. 3D geometry offers a complete view of fistula evolution over time, and in combination with MR velocity data offers the opportunity to perform detailed CFD investigations of local hemodynamics.

References: 1. Robbin M.L. et al, Radiology 2002, 225 :59-64 ; 2. Lomonte C. et al, Seminars in Dialysis, 2005, 18 :243-246;
3. Boussel L. et al, Stroke 2008, 39(11):2997-3002