Hemodynamic changes during arterio-venous fistula maturation. An MRI follow-up

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Introduction: The incidence of kidney failure increased dramatically due to the epidemic of diabetes. These patients require a permanent vascular access for dialysis therapy. Among the different access types, the autogenous arterio-venous fistula (AVF) has the highest patency and lowest infection rates; however AVF maturation, an active process of vascular remodeling, is very prone to complications, such as impaired remodeling, stenosis development, and insufficient flow. These complications eventually lead to failure [1, 2]. Hemodynamic parameters have a direct role in the vascular remodeling process in AVF maturation [3]. Investigating there parameters could help improve our understanding of fistula failure.

The aim of the current work was to evaluate the changes in vascular anatomy and local hemodynamic parameters during AVF maturation using MRI and Computational Fluid Dynamics (CFD).

Methods: Imaging was performed at 1.5T (Siemens Avanto, Erlangen Germany). The protocol consisted of a 3D time of flight (TOF) acquisition (TR/TE = 30/7 ms, FA = 25°, voxel = 0.25×0.25×0.6mm^3, BW = 158 Hz/pixel, NA = 1) to obtain the luminal geometry; followed by through-plane blood flow velocity measurements with a standard 2D phase contrast (PC) sequence (TR/TE = 29.5/4.1 ms, VENC = 150-250 cm/s FA = 30°, voxel = 0.78×0.78×5mm^3, BW = 391Hz/pixel, NA = 3). Velocity maps were corrected for background phase errors using a linear fit of the static tissue of the arm and for gradient field nonlinearities using a scanner specific theoretical field model [3].

To determine the changes in vascular anatomy over time, luminal areas were measured at 5 locations in the artery and 5 in the vein on TOF data from each time point, using the level of the anastomosis as a landmark to register subsequent measurements. For velocity fields and wall shear stress (WSS) analysis, computational fluid dynamics (CFD) simulations were performed using a finite volume solver, Fluent (ANSYS, Inc) in patient-specific geometries obtained by manual segmentation of 3D TOF. Flow boundary conditions required for the solution were obtained from PC-MRI.

Results: 3 patients underwent surgery for upper extremity fistula placement. The created fistulas were imaged immediately after surgery, 1 month, 3 months and over 6 months later (2 patients). As expected for 3D TOF, signal diminution was noted in venous structures; however the angiograms had sufficient quality to permit vessel segmentation and area measurements. Both vessels involved in the fistula presented modifications of the lumen geometry. The most noticeable changes occurred in the venous branch. The venous luminal area presented an increase at the early imaging points followed by a decrease at the last point (Figure1 left). Stenosis was detected in 2 patients at 6 and 8 months after surgery. Similarly, blood flow rate increased at early imaging points. It subsequently started decreasing at 3 months for 2 patients and at 6 months for the third (Figure1 right).

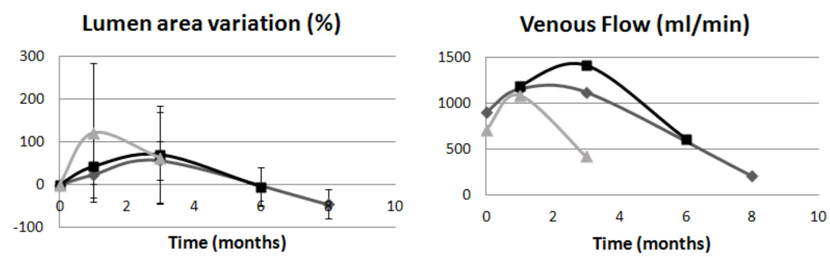

Figure1. Venous lumen area (left) and blood flow rate (right) changes during fistula maturation in 3 patients.

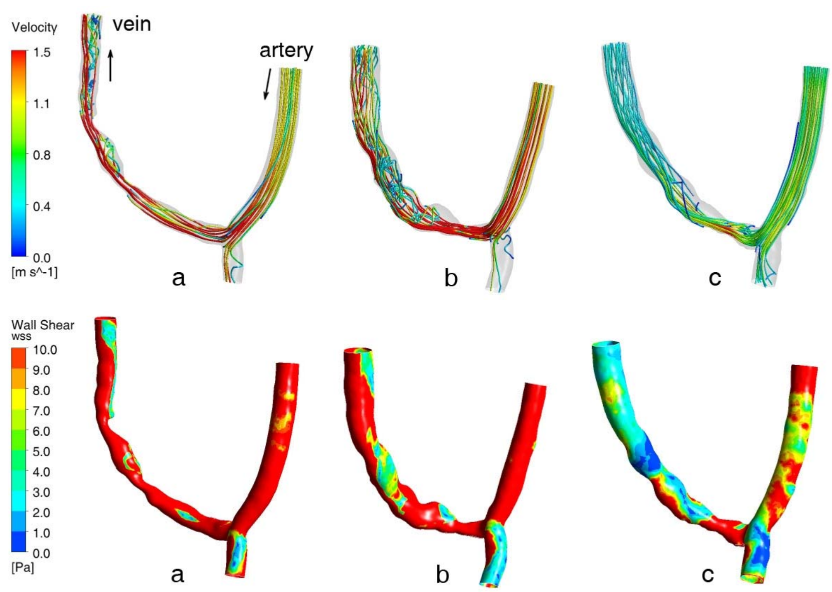

Figure2. CFD simulations at peak systole showing flow patterns (top) and WSS distributions (bottom) obtained 1 day (a), 1 month (b) and 3 months (c) after AVF creation, corresponding to patient (▲) in Figure1.

Comparisons of the flow fields and WSS distributions computed at peak systole for one patient immediately after surgery, 1 and 3 months later are presented in Figure 2. The streamlines in the venous segment show high velocity jets on the outer curvature of the vessel and recirculation regions at the inner curvature at 1 day and 1 month after surgery (panels a and b). This pattern changed into a more homogeneous velocity profile at 3 months (c). The increase in venous lumen area, most likely as an adaptation to the high WSS induced by fistula placement, resulted in smaller WSS values at the follow up points. It should be noted in this particular case, that flow through the anastomosis diminished at 3 months, thus the observed WSS reduction is related in part to low velocities.

Conclusion: We presented here preliminary results on evaluating changes in hemodynamic parameters during the AVF maturation process. Vascular remodeling seems to be driven by interdependent processes. An increase in luminal area as a response to the high blood flow rate results in an increase in blood flow, which in turn may result in further dilatation. MRI is the most suitable modality for the assessment of hemodynamic changes, as it provides an angiographic map and velocity measurements 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.** Higuchi T. et al, Nephrol Dial Transplant (2001) 16:151-155.**4.** Markl M. et al, Magn ResonMed (2003) 50:791-801.