High flow fistula imaging: A study comparing Bright-blood and Black-blood approaches

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Introduction

Patients suffering from End Stage Renal Disease (ESRD) are frequently treated using hemodialysis as a life-saving therapy. During hemodialysis blood is circulated through a dialysis filter with a flow of 200 – 400 ml pr. minute. To obtain the necessary blood flow from a vein, an arterio-venous fistula (a-v fistula) is created, typically between the radial artery and the greatest forearm vein (the cephalic vein), see fig. 1. An a-v fistula is essentially a shortcut between the high pressure arterial side (approx. 14 kPa) and the low pressure venous side (approx. 2 kPa) and conducts most of the blood flow directly from the feeding artery to the vein. Creation of an a-v fistula entails a profound change in the hemodynamic conditions and a dramatic increase of the blood flow in the involved vessels. Sufficient blood flow in the vein is in the magnitude of 600 – 800 ml per minute, but considerably higher flow is often seen in older fistulas, which have functioned over an extended period of time. High flow rates cause elevated wall shear stresses (WSS), frictional forces exerted on the endothelial lining of the vessel wall by the flowing blood. WSS is an important determinant of endothelial function and changes in WSS levels are highly associated with vessel dysfunction and disease, e.g. atherosclerosis (1). The surgical design of the fistula (i.e. the length and angle of anastomosis) severely influences the regional flow conditions and may therefore have great importance for a-v fistula complications, such as the development of a stenosis. The patency of a-v fistulas may be improved by analyzing the correlation between hemodynamic conditions and the surgical geometric design. Blood flows can be analyzed using Computational fluid dynamics (CFD), which provide a method for numerical analysis of blood flows in different kinds of vessel geometries based on 3 dimensional CAD models derived from MRI scans. Two types of MRI scans were performed and evaluated to obtain images with sufficient image quality for segmentation in order to generate 3D models for CFD simulations to evaluate flow and WSS in fistulas.

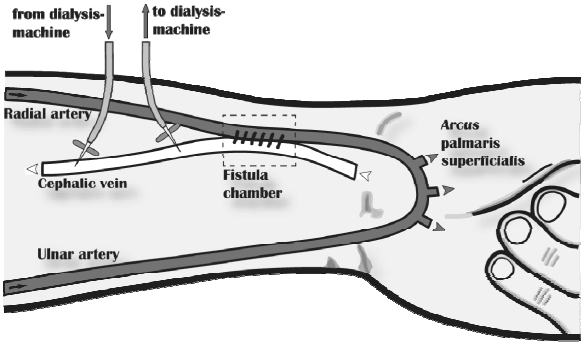

Figure 1, *Antebrachial vessel anatomy after the creation of an a-v fistula. Notice the naturally occurring collateral blood supply from the ulnar artery distally, which results in retrograde flows in the distal arterial segment of the fistula*

Methods

An idealized in vitro model of a fistula was created according to real fistula geometry as observed during surgery. The model has two inlets, two outlets, and an anastomosis part (fistula chamber). In order to simulate the chaotic and turbulent flow in the fistula chamber, mean steady flow of approximately 900 ml/min was applied to both inlets. All data acquisition was carried out on a Philips Achieva 1.5 T MRI scanner, with Nova Dual gradients and software Release 2.1.3. The model was scanned using Black-blood and Bright-blood techniques. During two scan sessions the model was scanned with either both inlets open or one inlet occluded, respectively.

Black blood:

A spin echo sequence was used employing a dual inversion prepulse. Sixteen slices were scanned using a 160 x 120 mm field of view (FOV), 256 x 240 matrix size yielding a resolution of 0.63 x 0.63 mm, slice thickness = 3 mm, slice gap = 4 mm, re-inversion slab thickness = 5 mm, inversion time (TI) = 333 ms, echo time (TE) = 8 ms, repetition time (TR) = 1 s, total scan duration 208 s.

Bright blood:

A T1 weighted gradient echo sequence was used to scan 16 slices employing a 160 x 120 mm field of view (FOV), 268 x 268 matrix size yielding a resolution of 0.6 x 0.6 mm, slice thickness = 3 mm, slice gap = 4 mm, echo time (TE) = 3.7 ms, repetition time (TR) = 9.98 ms, total scan duration 33 s.

Results

Figure 2 shows the images from the Black-blood and Bright-blood scans. The Bright-blood images show a marked lack of signal in the fistula chamber where the chaotic and turbulent flow is present. Moreover it was difficult to outline the vessel wall in the chamber. Figure 2 shows an example where it seems as if a vessel is branching, despite the fact that there are no branching vessels in the model. Black-blood images are not affected by the turbulent flow present in the fistula chamber.

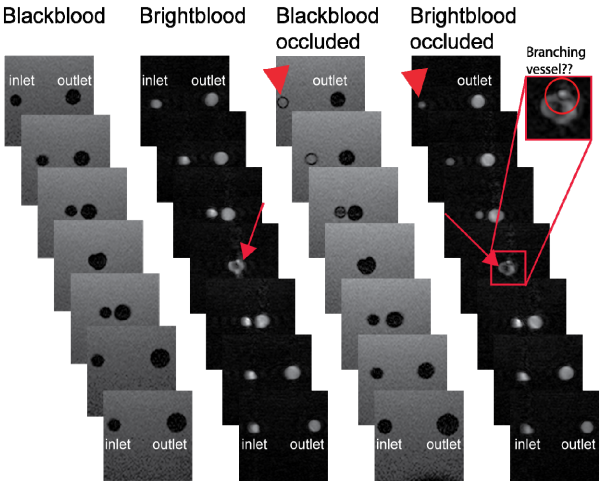

Figure 2, ***Arrows*** *show signal void due to chaotic and turbulent flow in bright blood images.* ***Arrowheads*** *show limited flows in the occluded limb in the bright and black blood images.*

Discussion

MR contrast agents are usually the method of choice to generate good image quality when performing angiographies. However, recent data (3) suggest gadolinium-based contrast agents may be relatively contraindicated in the ESRD population since it has been linked to the development of nephrogenic systemic fibrosis. To examine the development of patient fistulas in order to determine which hemodynamic conditions lead to patency problems, multiple scans are needed with corresponding increased exposure to contrast agents. A method which does not employ contrast agents would therefore be preferable in this population.

Bright blood TOF is usually used for generating geometries for CFD simulations due to the method's short acquisition time. However, in regions of turbulent or chaotic flow, always present in the fistulas of patients, bright blood imaging will often display signal voids complicating the post-processing of the images with regards to geometry generation. In these cases, Black-blood imaging, though more time-consuming, may be of help in geometry reconstruction due to the insensitivity of this method with regards to chaotic flow.

References

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