NMR Microimaging of Blood Flow

Motivation The goal of this project is the precise determination of the arterial blood flow in the region of abnoral modifications, such as aneurysms. The results are compared with hydrodynamical numerical simulations of the flow [1]. The combination of these two techniques will contribute to improved predictions of the effect of different potential interventions in patients suffering from aneurysms.

Figure 1: Example of an aneurysm.

The necessity for this project arises from the large number of patients suffering from aneurysms (> 300000 cases per year in Germany). Rupture of these aneurysms can lead to stroke and is often life-threatening. Possible treatments include the placement of stents. However, the success of these interventions is still hard to predict and the choice of the most suitable type of stent for a given patient is often difficult. Precise and reliable predictions of the effect of a stent on the blood flow in the affected region would lead to more informed decisions and higher probability for successful treatments. Numerical simulations of blood flow, on the basis of precise geometrical information, are becoming possible. However, the highly nonlinear nature of the hydrondynamical equations of motion makes it difficult to assess the reliability of these predictions. Comparisons to experimental data would be very useful for improving the reliability. Measurements of blood flow can be made, in principle, in clinical MRI machines [2], but the resolution of these instruments is much too low for quantitative comparison to the simulated dynamics. In this project, we therefore will rely on NMR microscopy [3], which can provide much higher spatial and temporal resolution.

Goals The project seeks to improve the understanding of blood flow dynamics in human blood vessels, with a particular emphasis on the effect of pathological changes like stenosis or aneurysms. Initially, we work on model systems and try to obtain quantitative data that can be compared to simulated flow data that are generated in the computer science department.

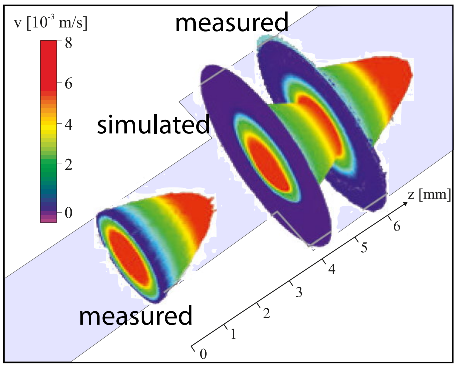

Figure 2: Comparison of measured and simulated flow pattern in a tube with variable diameter.

Fig. 2 shows, as an example, a comparison of measured and simulated flow data in a tube whose diameter changes from 3 to 6 mm.

We are currently working towards answering the following questions:

- What is the ultimate spatial and temporal resolution with which the flow can be measured?
- What are the necessary technical specifications that the NMR system has to meet?
- How can we improve existing experimental schemes for measuring flow?
- What are the requirements that models for arterial aneurysms have to fulfill?

Experiments The measurements are performed in an NMR microimaging system in a 600 MHz widebore magnet. Compared to clinical MRI scanners [2], this setup permits significantly higher spatial resolution, of the order of 10 μm, as well as better temporal resolution. Starting with water flowing through simple geometries, we develop the necessary pulse sequences for precise and quantitative measurements of the flow velocity as a function of time and space.

Figure 3 shows, as an example, the measured flow velocity distribution in a blood vessel model, whose geometry is shown on the left-hand side. The red areas correspond to high velocities, the blue to slowly moving fluid. As expected, the velocity is very low in the region of the aneurysm.

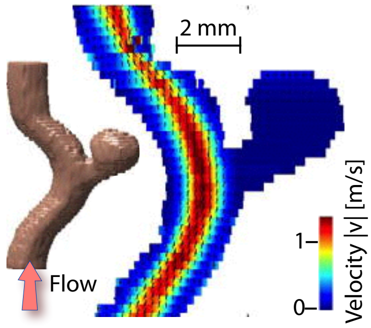

Figure 3: Measured flow velocities in a model blood vessel with an aneurysm. The left-hand part shows the geometry, as determined from MRI, and the right-hand side the absolute value of the flow velocity.

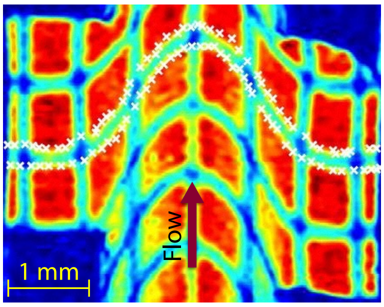

Figure 4: Time-of flight measurement of flow in a vessel with variable diameter.

To optimize the reliability of the measurements, we use different approaches to flow measurement. Fig. 4 shows, as an example, the time-of-flight approach. Here, two sets of parallel planes in orthogonal directions were marked by selective RF excitation pulses and measured after a delay during which the flow transported them by a distance proportional to the velocity. In this example, laminar flow conditions were used and the observed profile matches well with the theoretically expected parabolic profile.

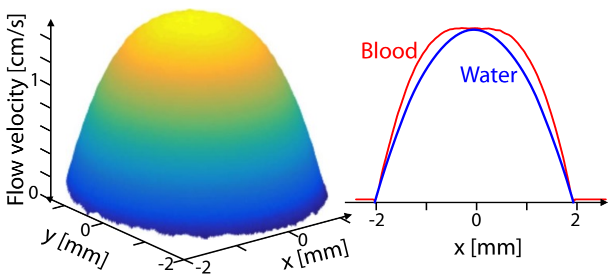

Figure 5: Velocity profile of blood flowing through a cylindrical tube. The left-hand side of the figure shows the two-dimensional velocity field of a plane perpendicular to the cylindrical axis. The right-hand side compares a cross-section with the parabolic velocity profile of water.

The flow behavior of blood differs from that of simpler fluids like water. In particular, its viscosity varies with the velocity gradient. This property is known as "shear thinning". As a result, the velocity profile does not correspond to the Hagen-Poiseuille profile of simple Newtonian fluids. Fig. 5 shows the flow velocity of blood flowing through a cylindrical tube, measured by phase-contrast encoding for the voxels of a selected plane. The profile is clearly flatter than the parabolic profile expected for Newtonian liquids. This is further verified by the cross-section on the right-hand side, which is clearls flatter close to the center of the tube and steeper close to the walls, compared to the profile of water.

References

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