Flow regulation in multi branched models of blood vessels

M. Ringelstein, A. Berthe, T. Schneider, U. Kertzscher, K. Affeld
Biofluid Mechanics Laboratory, Charité – Universitätsmedizin Berlin, Berlin, Germany, m.ringelstein@gmx.de

Experimental models are an important instrument for investigations of flow characteristics in blood vessels. For realistic conditions all essential branches of a vessel need to be simulated and controlled. An outflow controlling system was designed for a study on flow conditions in a cerebral aneurysm model with multi outlets. The volumetric flow varied between the outlets. The construction for regulating the outflow is based on the principle of communicating vessels. It was attached to the experimental setup and allowed a facile verification of the outflow conditions. It is now possible to adjust and monitor the designated flow rate visually in a simple, effective and low-priced way.

1 Problem

Models of blood vessels are important for the experimental investigation of flow phenomena, which cannot be observed directly. They cannot be observed, because blood vessels are sometimes inaccessible, too small or because blood is opaque. Models can be enlarged, observed freely and model fluid permit the use of advanced methods of flow visualisation and flow measurements. Experiments provide data for flow characterization and validation data for computational fluid dynamics simulations.

In general, flow models consist of two components: the actual anatomic vascular model and an actuator, which creates the flow of the model fluid.

Many blood vessels have complex shapes and contain various bifurcations. This means, that there is one inflow vessel, but more than one outflow vessel (Figure 1). The flow in all branches has to be controlled during the experiments according to prior specified values. The most obvious solution is to connect each vessel branch with a volumetric pump, in which the flow rate can be determined. However, the use of several suction pumps needs a complicated adjustment and synchronization and is expensive in acquisition. Furthermore it occupies a lot of space in laboratories.

Volumetric flow sensors are also expensive and require customization for different fluids.

The objective of this paper is to show a simple and practical solution for this problem.

2 Methods

The proposed solution for this problem is an experimental setup based on the principle of communicating vessels. This flow system contains two or more cylinders each connected to the respective outflow vessel. Each cylinder simulates the resistance behind one branch of the vascular model.

The volume of the fluid in a cylinder is \( V = h \cdot \left(\frac{\pi}{4}\right) \cdot d^2 \). The fluid height (\( h \)) is supposed to be always equal in all cylinders. This makes a visual observation of the outflow possible. To achieve that, the diameter (\( d \)) of each cylinder must be adapted to the specific volumetric flow in each branch (Figure 2).

A simple setup of transparent acrylic pipes attached to a flat basis and connected to the branches is used to define the requested volumetric flow.

Figure 1: A volumetric flow splits at a bifurcation of a carotid artery into two flows of different value (\( V_1 < V_2 \)). \( V \) is the volumetric flow in ml/min.

Figure 2: Principle of flow regulation for multi branches with communicating vessels system.
It is possible to use available pipe sizes and fill their volume with smaller rods to obtain intermediate volumes (Figure 3). This construction allows an optic outflow control without further sensors and with only one pump.

The dynamic pressure differences caused by differing lengths and diameters of the connecting tubes between anatomic model and the controlling construction were compensated by attached squeezing valves. Therefore the fluid surfaces rose equally. Even the impact of resistance in the smallest vessels was balanced out.

<table>
<thead>
<tr>
<th>Branch</th>
<th>Vessel</th>
<th>$V$ in %</th>
<th>$V$ in model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet</td>
<td>Arteria carotis interna</td>
<td>100.0</td>
<td>444.0</td>
</tr>
<tr>
<td>Out 1</td>
<td>Arteria ophtalmica</td>
<td>0.6</td>
<td>2.6</td>
</tr>
<tr>
<td>Out 2</td>
<td>Arteria communicans posterior</td>
<td>13.1</td>
<td>58.2</td>
</tr>
<tr>
<td>Out 3</td>
<td>Arteria anterior cerebral</td>
<td>52.2</td>
<td>231.8</td>
</tr>
<tr>
<td>Out 4</td>
<td>Arteria choroidea anterior</td>
<td>0.5</td>
<td>2.2</td>
</tr>
<tr>
<td>Out 5</td>
<td>Arteria cerebri media</td>
<td>33.6</td>
<td>149.2</td>
</tr>
</tbody>
</table>

Table 1: Branches of the cerebral aneurysm with the corresponding vessels and flow rates.

4 Conclusion

To the best of our knowledge there is no comparable simple solution for the control of the outflow. The noncontact measurement system with cylinders works for a multi branched experimental setup with reservoir. The actuator may pump or draw the fluid. The possibility to check the flow rate visually simplifies the setting and adjustment. The accuracy of visual monitoring is limited. This error source could be compensated with float gauges if necessary.

The system with cylinders only needs the adaption of squeezing valves which would be necessary with flow sensors too.

The system is durable and not expensive. It is relatively small and simple to design. The cylinders allow the control of stationary and pulsatile flow and enable the withdrawal of test fluid after a sampling.

The regulation system is very adaptable and applicable to other experimental setups with multi branched models for example arterial system models or aortic arch models.