Time resolved flow measurement in the isolated rat heart - characterization of the left coronary artery stenosis

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Synopsis

For quantification of blood flow velocities, phase contrast imaging techniques have been validated in several studies [1]. Most applications focus on large vessels such as the aorta, carotids, or femoral arteries. This is due to the fact that systematic errors strongly increase with decreasing number of image pixels that cover the vessel lumen [2]. The purpose of the present study is to demonstrate that the flow behavior in small vessels such as the coronary arteries can be quantified in the isolated rat heart with high-resolution 2D phase contrast MRI experiments. In addition the flow behavior in hearts with acute stenosis was investigated and the degree of stenosis was quantified.

Methods

Hearts of male Wistar rats were excised and perfused in the Langendorff mode with oxygenated Krebs-Henseleit buffer. Coronary flow was measured by an ultrasonic flowmeter, and left ventricular pressure was measured using a balloon inserted in the left ventricle and connected to a pressure transducer. The time dependence of the pressure curve was recorded with a personal computer, which also generated trigger pulses to synchronize the MR pulse sequence to the heart cycle.

MR imaging was performed on a Bruker AMX-500 microscopy system at 11.75 T. 3D time of flight angiography was performed prior to flow measurements to obtain anatomical information. A segmented flow-compensated 3D-FLASH sequence with a TR/TE of 3.0/1.3 ms and a flip angle of 30° was used for angiography (isotropic resolution: 140 µm). For visualization of the vessel structure an isosurface reconstruction was used (Amira Graphics Software Package), after zero-filling the raw data.

A phase contrast cine-FLASH imaging method was used for flow quantification with the following imaging parameters: FOV: 18 x 18 mm, Matrix: 256 x 256, spatial resolution: 70 µm in plane, slice thickness: 500 µm, TE = 2.3 ms, 10 images per heart beat. Flow encoding was achieved through a bipolar gradient in slice direction. 5 different flow encoding steps were applied in a total acquisition time of 4 minutes.

Results

Figure 1a shows a 3D visualization of diastolic velocity profile of the left coronary artery. In the presented example the diameter of the vessel was determined to 490 µm and the maximum flow velocity was calculated to 15.3 ± 2.4 cm/s, whereas the mean velocity was calculated to 7.6 ± 3.7 cm/s. In Figure 1b the time dependence of coronary flow during heart cycle is shown. An isosurface reconstruction of a part of the left coronary artery containing the stenotic area is shown in Figure 2a. The luminal narrowing of the coronary artery can clearly be detected. The consequence of this narrowing is an increase of flow velocity in stenosis what can be seen in Figure 2b.

Discussion

Our results show that high-resolution phase contrast imaging allows the quantification of flow velocities in the coronary arteries of isolated rat hearts without the need of partial volume corrections. The parabolic flow behavior inside the coronary artery can clearly be seen (Fig. 1). The coronary flow depends on the heart cycle and shows a good correlation between flow velocity and left ventricular pressure. In diastole, where the left ventricular pressure reaches a minimum, the coronary flow shows a maximum, whereas in systole the left ventricular pressure reaches a maximum and the flow velocity a minimum (Fig. 1b).

In stenosis no turbulent flow was observed, however an increase of flow velocity was always detected (see Fig. 2b). This increase in flow velocity is caused by a reduction of the cross section in the stenotic area of the coronary artery. Consequently, the increase of flow velocity reflects the degree of stenosis. The ratio of flow velocity above stenosis and in stenosis behaves inversely proportional to the corresponding cross sections: $A2/A1 = v1/v2$.

Table 1 summarizes the degree of stenosis obtained from the cross section and from the change in flow velocity for 4 hearts with acute stenosis. These results show that the increase in flow velocity is in good agreement with the decrease in cross section and thus it is possible to make a prediction of the degree of stenosis with phase contrast flow measurements.

Acknowledgements

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References

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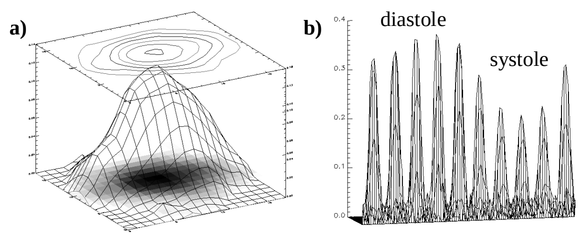
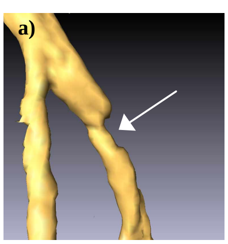


Figure 1: 3D visualization of diastolic velocity profile (a) and time dependence of coronary flow during heart cycle (b)

Table 1: Degree of stenosis

heart	A2/A1	v1/v2
1	0.66	0.68
2	0.63	0.65
3	0.57	0.58
4	0.60	0.59



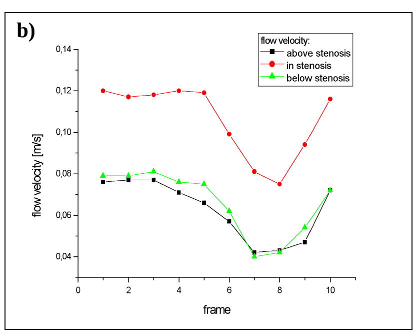


Figure 2: Isosurface reconstruction of a stenotic region (a) and mean flow velocity dependence during heart cycle (b)