Blood flow measurement: are artificial tracers necessary?

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Blood flow measurements have become an indispensable technique to study fundamental biological processes in vivo. In particular measurements using microscopic Particle Image Velocimetry (micro-PIV) have provided insight in the development of a range of model systems, including zebrafish, chicken embryos and the rat mesentery. An open question in these studies has so far been whether the use of artificial tracers particles is required, or if e.g. red blood cell are an acceptable alternatives.

In this study, we extend earlier work by performing a direct in vivo comparison at two (exemplary) magnifications in the chicken embryo model system. For “medium” magnification (here 12.5x), red blood cells and artificial tracers give the same results in terms of velocity fields. An example is given in figure 1. For “high” magnifications (here 25x), differences up to a factor 2 can be observed, with tracer particles yielding consistently higher velocities. An example is shown in Figure 2. The tracer particle results are closer to the expected values, based on in vitro reference measurements. This indicates that the use of red blood cells leads to a significant underestimation of the true blood flow in this case.

These outcomes can be understood by evaluating the depth-of-correlation for each case. In the “medium” case, the depth-of-correlation for the experiment using red blood cells (approx. 8 μm in diameter) is significantly larger than in the experiment using artificial tracers (1 μm). However, both are much larger than the thickness of the flow geometry (in this case e.g. the blood vessel diameter). For the “high magnification” case, the two depths-of-correlation are still different, yet now of the same order of magnitude as the blood vessel diameter. Averaging along the optical axis is therefore different for the artificial tracers and the red blood cells, leading to differences in the measured velocity (and thus derived parameters such as flow rates and wall shear stresses).

We present a relatively simple method to determine if an experiment facility is operating in the so-called depth-saturated regime. Measurements in this regime can be directly translated to e.g. the “true” centerline velocity by a correction factor. Experiments in the non-saturated regime will remain difficult to interpret and should be avoided, unless very thin depths-of-correlation can be obtained, so that only a well-defined plane is measured.

Fig. 1 at relatively low magnification, artificial tracers and red blood cells give nearly identical results. In this case, both measurements are in the depth-saturated regime and underestimate the real flow by the same amount.

Fig. 2 at higher magnification, red blood cells results can be a factor two smaller than tracer-based results. In this case, the depth-of-correlation for both cases of the order of the blood vessel diameter and differences between the particle types becomes apparent.