Tracking Micron Sized Particles as a Means to Validate Bacterial Motion in Flowing Tubes

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Introduction:

MRI has been demonstrated to be a non-invasive technology capable of producing physically realistic, visually informative and quantitatively precise images of flowing material [1]. The following are some of the advantages of using MRI for fluid dynamics as compared to other techniques: (i) absolute velocity measurements; (ii) no limitation on liquid viscosity; and (iii) it can be used on clean and unclean liquid mediums. The goal of this study is to perform a complete fluid dynamic analysis and modeling of a flow channel (a U- tube) using MRI and computational fluid dynamics (CFD). A mini-flow channel is developed which can be used to accumulate bacteria at high concentrations in order to be detected by an internal Biosensor. Although several groups have much published data on 3D flow measurements, our goal is to mimic the accumulation of bacteria by using micron sized iron particles and track their streamlines in the channel. We hypothesize that the signal loss caused by the particles will aid us in visualizing the tube fluid dynamics and hence tracking the potential bacterial pathway [2]. By injecting these particles into the streamlines, we were able to validate CFD predictions for the bacteria using the commercial CFD-ACE+ software.

Materials and Methods:

All MR imaging was performed on a 4.7T Bruker animal magnet with a simple U-shaped glass tube. Spin echo velocity imaging (SEVI) was used to extract velocity profiles from the inlet and outlet sections of the phantom. The experimental set up consisted of an open water loop with the U- tube flow channel connected to a Cole Parmer (65mm-single float) flow meter via plastic tubing. Transverse sections were obtained with the following imaging parameters: TR = 50ms, TE = 10ms, in-plane resolution = 312µmx312µm, TH = 3mm and the number of velocity encoding steps were chosen to be 16. Four experiments with different flow meter settings were performed (1.32cc/s, 2.26cc/s, 2.66cc/s and 3.08cc/s). The flow encoded images were processed using the macro ProcRhea (courtesy Bruker Biospec Inc) and the velocity maps extracted [3]. The processed velocity images were read using SPIN a custom written software. Velocity profiles were plotted across the diameter of the U- tube, average and peak velocities were calculated by selecting a region-of-interest based on the diameter of the tube. Transient incompressible flow simulation module was used and the time-dependent continuity equation, pressure-based Navier–Stokes equations, and energy balance equation were solved concurrently to generate velocity profiles. Theoretical flow profiles were obtained by solving the basic Poiseuelle equations. In both cases, the experimental conditions were used as boundary conditions. In order to visualize the iron micro-particles, a fully flow compensated gradient echo (GRE) sequence was used with TR = 25ms, TE = 4ms, FA = 13°, in plane resolution of 391x391µm, and TH = 3.5mm covering the entire phantom coronally. During the time the micro particles were injected manually, 20 slices were collected, one every 4 seconds. Reference images were collected with no beads present. By subtracting the phase images between reference flow and particle flow, the path of the particles in the streamlines were compared with the results generated by the Spray Module in CFD-ACE+ with similar boundary conditions.

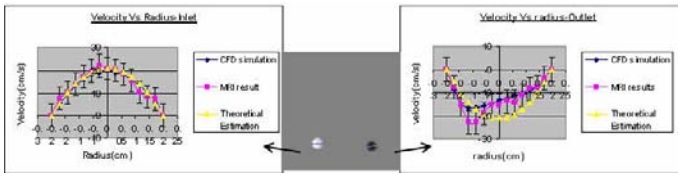

Fig 1: Velocity profiles at Inlet and Outlet with a flow of 1.32cc/s

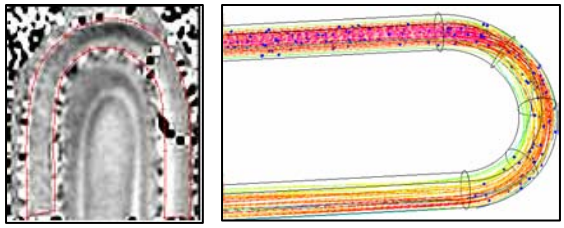

Fig 2: left - MR phase map and right – CFD calculation

Results:

MR generated flow profiles were in good agreement with the CFD simulations and the Poiseuelle flow estimation (Fig. 1). The direction of the velocity vectors is represented as positive and negative signs in the encoded MR images at the inlet and outlet respectively. We observed asymmetrical velocity profiles in the outlet section immediately after the U-bend which can be attributed to the effects of convective acceleration. Mean percent errors in the flow rates measured from MR results at the inlet and outlet were *4.58%* and *6.75%*, respectively. A 150 micro liter injection of magnetic iron beads caused around 50% signal loss with an echo time of 5ms making it possible to visualize a range of particle densities in the flowing tube (Fig. 2, left). The CFD simulated results (Fig. 2, right) indicates that the beads are thrown towards the outer wall of the tube as expected. This agreement was seen in multiple experiments with different concentrations of the particles injected into the streamline.

Discussion and Conclusion: We were able to extract velocity and particle profiles from MR imaging in good consistency with the CFD simulated and theoretical generated results for a U-shaped tube. We established a novel method of using micron sized iron particles to investigate the complex flow profiles in the bend of the tube. All these results will help in positioning the biosensor inside the channel to capture the highest concentration of bacterial sample to ensure the optimal detection of the microbes.

Reference:

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