Perfusion Phantom for Quantitative Imaging

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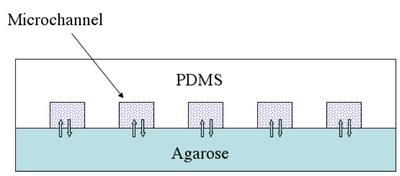
Introduction:

A perfusion phantom with unique features and a wide variety of applications in MR and other imaging modalities is presented. The phantom is especially suited to tissue perfusion simulation with diffusible and non-diffusible MR tracers. A network of micro-channels in the scale of actual capillaries replicates the blood flow in tissues. Using microfabrication technique, networks with any desired pattern can be generated. Since the geometry of networks is known, flow rate, delay, dispersion and other fluid parameters can be exactly calculated, using finite elements numerical methods. These calculated results can be used to investigate the accuracy of experimental measurements and the precision of mathematical models.

Methods:

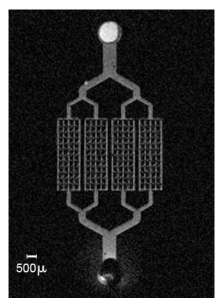
Agarose and PDMS have been used to simulate tissue characteristics by several research groups [1-5]. MR parameters of Agarose, including T1 and T2, can be set close to these values in human tissue by adding impurities to the gel. Agarose is a porous gel and the size of the pores is a function of the gel concentration. Due to this characteristic of its texture, it can be considered as an appropriate media for diffusible tracers and water exchange studies. Last year a purely Agarose phantom was presented by our group. Our experimental results showed a clear water exchange between the gel and micro-channels. Agarose implies some restrictions on the network design, including the size of the channels and their geometry. Our old phantom was made of many straight parallel channels 160, 200 or 300 micron in diameter. Using PDMS we have overcome many of these shortcomings.

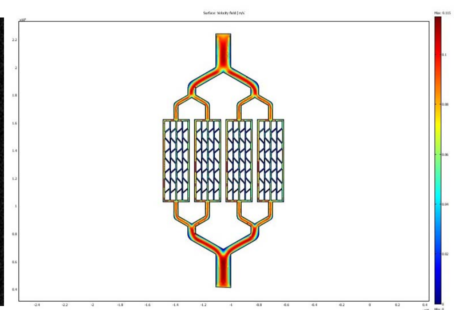


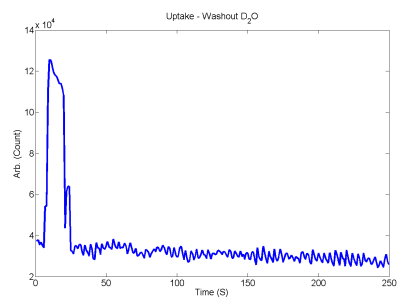
Polydimethylsiloxane **(**PDMS) is a nontoxic gel which is used in microfabrication. Using micro-fabricated molds, micro-channels in the range of few to few hundred microns with any desired pattern can be generated in PDMS. Flow characteristics in these microchannels are very similar to hydrodynamic characteristics of blood in capillaries. Purely PDMS phantoms provide an ideal tissue samples for perfusion studies using non-diffusible tracers. A two component phantom, with a substrate of Agarose and micro-channels network of PDMS (figure 1) not only has the capability of simulating the fluid dynamic in capillaries, but also has the potential to mimic small particles and water exchange between blood and the tissues. Figure 2. (right) shows an extremely high resolution MR image of a 16x25 mm purely PDMS phantom. It has four generations of capillaries, 50-1000 microns wide. Figure 3. (right) shows the calculated flow rate using COMSOL, a finite element based program.

Results:

To show the similarity of the phantom to actual tissues in response to MR tracers, the uptake-washout curve was measured. A control image was taken when water was running through the phantom at the rate of 80 ml/h, using a presystolic pump, which also caused the oscillations in signal. Then a bolus of 0.5 cc of deuterium oxide was injected to the hose supplying the phantom. Figure 4 shows the control value subtracted by the signal value during 250 seconds of measurement. The beginning of the graph shows the major uptake and washout; however, the full washout and recovery of the signal took much longer that could have been because of the very slow flow at the hyperfine channels.







Images were taken using a 2T Varian NMR/MRI machine with a hand-made surface coil. The two dimensional architecture of the phantom justifies using a surface coil to improve the signal to noise ratio. As mentioned before, PDMS is a silicone based gel. A large NMR signal from silicone, very close to the water signal, was observed which was removed by taking advantage of the short T2 of silicon.

Discussion:

A phantom for perfusion studies has been proposed which has unique capabilities for MRI and particularly perfusion studies. Perfusion occurs in a network of micro-channels that are in the same size scale as the actual capillaries. The phantom shows an up take - wash out characteristic very similar to that in tissues. Using this phantom, experimental results and mathematical models accuracy can be precisely investigated.

References:

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