A Perfusion Phantom for Diffusible and Non-diffusible MR Tracers

B. Ebrahimi[1,2], S. D. Swanson[3], and T. E. Chupp[2,4]

[1]Biomedical Engineering, University of Michigan, Ann Arbor, Michigan, United States, [2]Focus Center, Ann Arbor, Michigan, United States, [3]Radiology, University of Michigan, Ann Arbor, Michigan, United States, [4]Physics, University of Michigan, Ann Arbor, Michigan, United States

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. Also, the large density and flexibility of the geometry of the capillary network makes it suitable for perfusion studies with and without delay and dispersion effects. After minor developments, the phantom will be capable of simulating a variety of vascular diseases including vascular stenoses.

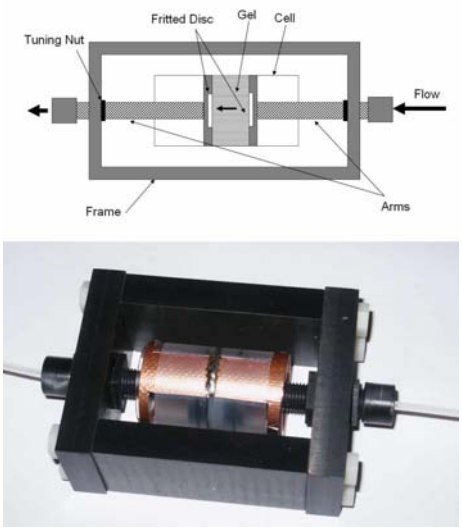

Figure 1. The phantom setup. The schematic plot showing different parts of the system (top) and the actual picture (bottom).

Methods:

Agarose and Sephadex have been used to simulate tissue perfusion by several research groups [1-4]. The MR parameters of these gels, including T1 and T2, can be set close to these values in human tissue [4]. These parameters can be controlled by adding impurities or using gels with different concentrations. These gels, due to their porous texture, can be considered as appropriate approximations for tissues in perfusion studies. Purely gel phantom is suitable for single compartment model simulations. Using Agarose and Sephadex beads, multi-compartmental systems can be investigated as well. To create a capillary network, acupuncture needles (SEIRIN type-J), 160-300 μm in diameter, were used. Different network geometries from simple parallel capillaries to complicated networks are achievable by this approach. The density of capillaries depends on the density of the holes in the mesh used. We have been able to make up to 100 capillaries / cm^2 using a rectangular mesh. The large density of capillaries increases the flow-gel contact surface and facilitates the chemical exchange.

Figure 1 shows the phantom setup. The gel sample is placed inside the cell, which is a glass tube 25 mm in diameter and 50 mm in length. Two arms are set to apply a tunable pressure on the gel. Applying a tiny pressure, the gel was sealed to the cell walls, preventing any flow from the outside of the sample even when high pressure syringe drivers were used. The inner side of the arms, where they come in contact with the gel, is also sealed with O-rings to prevent any leakage to the outside. Two nuts on the arms are used to fine-tune the pressure as well as the cell placement in the frame. Each of the arms can move up to 45 mm horizontally to accommodate gel samples with different thicknesses. A 15 mm extra-coarse fritted disc (150-200 μm pores) is placed on the inner-side of each arm. They distribute the water over the capillaries uniformly. The flow rate can be set using any pump or syringe drive. The resistance and the flow rate can also be controlled via the number and the diameter of the capillaries.

Results:

To show the diffusion in the phantom and to avoid the background signal, the sample of Agarose gel was made of 2% Agarose (type I-B, Sigma) and deuterium oxide instead of water. Figure 2 shows a 256 by 512 image of the water perfusion and diffusion distribution obtained using a hand-made copper probe seated around the cell in a 2 Tesla Varian system. Water at a flow rate of 60 ml/100gr/min was passed through the capillaries of the sample for a few minutes. As mentioned before, the flow only perfuses into the central core where the capillaries are in contact with the fritted disc. A simple calculation shows, and the MR image confirms, that the diffused water covers the area spanned by the capillaries in about a minute. At this point, the flow was stopped. From then on, perfusion no longer occurs and the change in the water distribution is due to diffusion alone. The second image was taken an hour later and shows the diffusion of water to the surrounding area..

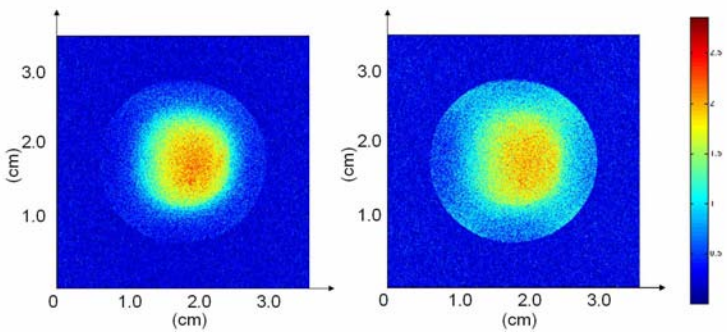

Figure 2. Perfusion and diffusion of water in a deuterium oxide sample (left) and pure diffusion – one hour later (right).

Discussion:

A phantom for perfusion studies has been proposed which has unique capabilities for perfusion MRI studies. Perfusion occurs in a network of capillaries that are from a hundred to a few hundred microns in diameter. Also, this network increases the flow-tissue contact surface, which results in an observable exchange between the capillaries and the gel. These act as intra-vascular and extra-vascular compartments, respectively. Over time, the exchanged tracer will redistribute itself in the gel as a result of diffusion.

References:

[1] B. P. Hills, K. M. Wright and P. S. Belton, *Molecular Physics*, Vol. 67, No. 1, 193-208, 1989
[2] X. MA, G. T. Gullberg, D. L. Parker, *Magn Reson Imag*, Vol. 13, No. 4, pp. 581-598, 1995
[3] E. M. Johnson and W. M. Deen, *AIChE Journal*, Vol. 42, No. 5, 1220-1224, May 1996
[4] H. Katoa, M. Kuroda, K. Yoshimura, A. Yoshida, K. Hanamoto, S. Kawasaki, K. Shibuya, S. Kanazawa, *Med. Phys.*, 32-10, pp. 3199-3208, 2005