A Simple and Cheap Perfusion Phantom

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Introduction: Optimization and validation of new dynamic contrast-enhanced (DCE) MRI sequences requires image acquisition of volunteers during contrast agent (CA) administration. This is in a practical sense not always feasible due to ethical and financial constraints. However, even if CA is used in volunteers, the pharmacokinetic (PK) behavior in healthy tissue is different to that in in lesions. Furthermore, repeatability of a volunteer experiment is difficult due to varying physiological conditions. A solution to these problems is to use a perfusion phantom. However, there is a lack of perfusion phantoms in the MR community. Only few publications exist[1,2,3] and few phantoms are commercially available or are in general difficult to rebuild. In this work, a simple and cheap perfusion phantom is presented. Contrast-enhanced signal changes similar to those in human tissue are mimicked and quantitatively described.

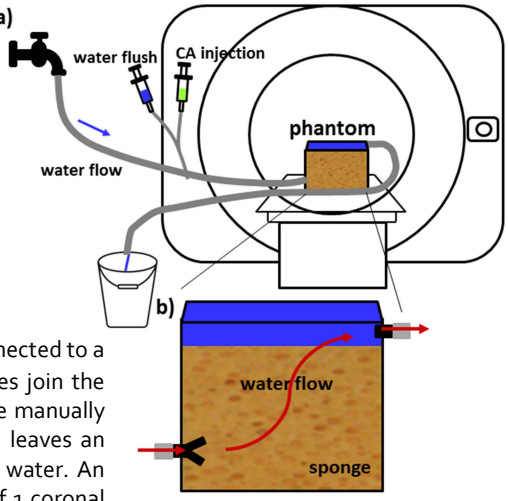

Figure 1: Experimental setup

Methods: The experimental setup of the phantom is shown in figure 1. The phantom is connected to a water source delivering constant water flow. In close proximity to the phantom, two syringes join the main hose via a valve. One is filled with CA, the other with water to flush the bolus. Both are manually injected. The hose is connected to the bottom of a plastic box containing a sponge, which leaves an unfilled area at the top. CA travels through the sponge and is washed out by newly arriving water. An outflowing hose directs the water into a bucket outside the scanner. A dynamic time series of 1 coronal slice is acquired using a T_1-weighted GRE sequence. The signal time curves can be described using a gamma-variate function[4] :

$\Gamma(t) = \varepsilon$ for $t \leq \tau$ and $\Gamma(t) = \varepsilon + (\Gamma_{max} - \varepsilon) e^{\alpha\left(1-\frac{(t-\tau)}{(t_{max}-\tau)}\right)} \left(\frac{(t-\tau)}{(t_{max}-\tau)}\right)^{\alpha}$ for $t > \tau$. Example fits are shown in figure 2. $\Gamma(t)$ is fitted to the dynamic curve of each pixel to generate PK maps. To test the reproducibility of the phantom, the experiment is repeated twice and joint histograms of the resulting PK maps of both repetitions are generated and Pearsons's correlation coefficient r is calculated for each parameter.

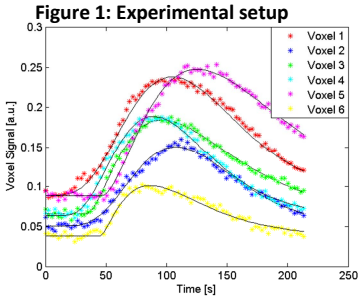

Figure 2: Example curves of single pixels and Γ(t) fit

Results: The resulting PK parameter maps of the parameters are shown in figure 3. They show heterogeneous parameter distributions with clusters of similar PK parameter values. The joint histograms of the two repetitions are shown in figure 4. For all parameters, the joint histograms are oriented along the diagonal. r is large for ε, Γ_{max} and t_{max}, and smaller for τ and α.

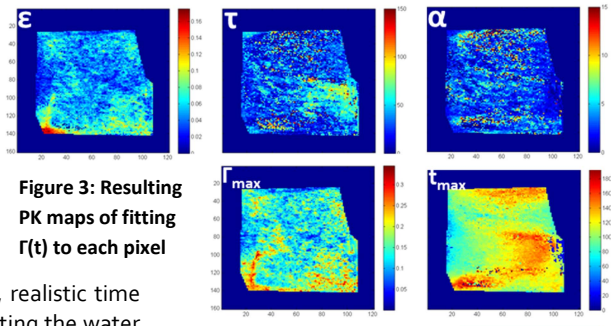

Figure 3: Resulting PK maps of fitting Γ(t) to each pixel

Summary and Discussion: A perfusion phantom allowing contrast agent administration is developed for sequence optimization and validation. PK maps can be generated by fitting the gamma-variate function to the data. The PK maps are relatively well reproducible. Derivations between repetitions arise from the manual CA injection, which introduces motion artifacts and inaccurate injection timings and rates. This error source can be eliminated by using a power injector. Additionally, with each repetition CA accumulates in the sponge, leading to a slight change in the baseline and PK properties of the phantom. Here, the employed sponge is just a normal cleaning sponge and could be replaced by a more sophisticated structure with a known ground truth, for example using a 3D printer as suggested by[5]. Compared to *in vivo* data, realistic time scales (3-4 minutes) similar to contrast changes in tumors can be achieved by adjusting the water flow rate to the flow velocity of large vessels. In reality, tumors are heterogeneous structures with varying physiological properties. Due to varying densities of the sponge, this is as well the case for the phantom. The phantom can be described using a gamma-variate function, which is often used to model physiological processes[6,7]. However, typical DCE MRI data are better described using multi-compartment models[8] with a slower wash-out. In the next steps the phantom could be extended to mimic such curves, for example using an additional filter on top of the sponge.

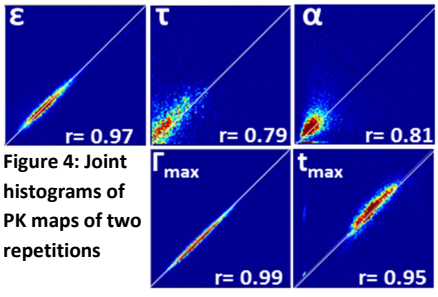

Figure 4: Joint histograms of PK maps of two repetitions

References: 1) Ebrahimi B , et al.IEEE.2010;57:1730-36.2) Driscoll, et al.Med Phys.2011;38:4866-803) Freed M ,et al.Med Phys.2011;38:5601-11.4) Chan A, et al.IEEE.2004;1067-1070.5) Oliver-Taylor A, et al.Proc Brit Chap ISMRM 2011. 6) Zhu Y, et al.SPIE Proceedings 2011; 7963.7) Benner T., Magn Reson Imaging.1997;3:307-17.8) Tofts PS, et al.Magn Reson Med.1991;17:357-267