Introduction: Dynamic contrast enhanced (DCE) MRI is a powerful, non-invasive tool for the detection, staging, and monitoring of cancer in vivo. In principle, DCE-MRI measures fundamental, physiologic parameters related to tissue microvasculature and composition that are relevant to the mechanisms of cancer proliferation. However, quantification of these parameters is hindered by image data acquisition limits vis-à-vis the tradeoff between spatial and temporal resolution. Additionally, there is still debate in the literature about which DCE signal model(s) best reflect(s) the image time-course data (Buckley, Yankelev). To explore these issues, a three-compartment phantom was constructed to simulate the DCE-MRI experiment under a range of conditions and, thus, better define the relationship(s) between true parameter values and those derived from data acquired with current DCE-MRI protocols.

Materials and Methods: Semi-permeable hollow fibers were harvested from a commercial dialyzer (Fresenius Optiflux F160NR; ID = 0.200 mm; OD = 0.280 mm) and used as phantom blood vessels. Seventy-five fibers were bundled together with heat shrink tubing to minimize the mean distance between fibers. Epoxy was applied to bond the fibers together at each end of the phantom (eliminating flow in all but the lumen of the fibers) and to attach the heat-shrink shroud to luer-lock attachments. With the multi-fiber phantom in the scanner magnet, flow was driven via a peristaltic pump situated remote from the magnetic field. A second phantom was constructed of a single fiber suspended in a capillary tube. Again, epoxy was used to secure the ends of the fiber to the capillary and to attach the capillary to luer-lock adapters.

MR experiments were performed with the long axis of the phantoms running parallel to $B_0$, thus minimizing susceptibility effects. All experiments were performed at 4.7 T using slice-selective imaging and spectroscopy, with the slice oriented perpendicular to $B_0$. Thus, time of flight effects could be used to suppress signal from media flowing through the fiber lumen. The multi-fiber phantom was filled with water and T1-weighted images of a single slice were acquired with and without media flow (TR = 500 ms, TE = 20 ms, NT = 64, data points = 128×128, FOV = 3.2×3.2 mm2, THK = 0.5 mm; Figure 2 top). Time resolved, slice-selective spectroscopy experiments were then performed to simulate the DCE-MRI experiment under near-idealized conditions (TR = 1 s, TE = 10 ms, NT = 1, temporal resolution = 1 Hz). Under these acquisition conditions, which signal from media in the lumen is suppressed, a controlled input function was introduced (square input function of duration = 10 min; max concentration = 1 mM MultiHance; Figure 2 bottom).

In single-fiber phantom experiments, with media absent MultiHance, T1 was measured spectroscopically (180-TI-90-TE/2-180-TE/2-collect) on a single slice with and without flow (30 TI values exponentially spaced from 0.10 to 15 s; PD = 4 s; TE = 30 ms; NT = 32; data points= 128×32, FOV = 2.56×0.64 mm2, THK = 2 mm; Figure 3 bottom, cropped to show only the region of interest). Subsequent imaging, under similar acquisition parameters, shows clear T1-weighted contrast between fiber wall and extra-fiber compartments (Figure 3 bottom, TI = 0.91 sec).

Conclusions: A phantom has been developed that provides a platform for carrying out DCE-MRI experiments under a variety of conditions, from near-ideal to those mimicking current in vivo protocols. Time-of-flight effects allow the intra-lumen signal to be suppressed in the presence of lumen flow and, thus, the kinetic characteristics defining contrast-agent diffusion through the fiber walls into the extra-lumen space to be quantitatively assessed. The phantom will provide a test bed for assessing the quantitative limits of DCE parameter estimation.