Assessment of system linearity and response to input parameters in a Dynamic Contrast-Enhanced (DCE) MRI phantom

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Introduction: Evaluation of contrast agent (CA) uptake curves from DCE-MRI protocols is an established approach to aid diagnosis in cancer imaging. However, whilst prospective QA can verify the linear relationship between signal intensity and CA concentration, there is a need to assess whether DCE-MRI sequences correctly evaluate CA concentration as a function of time. Recent commercial DCE-MRI test objects model complex dynamic behaviour, but require a physiological flow pump and may be impracticable for routine QA use [1]. In contrast, we have presented a novel and inexpensive DCE-MRI test object with established system reproducibility [2]. To expand the potential of this test-object as a useful QA tool, we now evaluate system linearity and investigate system response to input parameter variation.

Materials & Methods:

Experimental Set-up: The test-object consists of a 40 mm internal diameter (ID) sphere with four interconnected chambers with liquid input and output, with the input (3 mm ID) connected to an automated clinical MR injector system (Spectris Solaris EP, MEDRAD) to control flush flow and CA injection (*see Figure 1*). Flush and CA injection syringes were filled with Gadolinium-based CA solutions (Dotarem, Guerbet) ([Gd] = 0.11mM (115 mL) and [Gd] = 4.68 mM (65 mL), respectively), with concentrations chosen to give physiological T_1 values of 1300 ms (unenhanced blood) and 50 ms (enhanced blood), respectively. A standardised injection protocol was adopted, producing laminar flow: [i] 5 mL flush at 0.15 mL/s; [ii] 2 mL contrast at 0.5 mL/s; [iii] 70 mL flush at 0.15mL/s. After each scan only the flush syringe was refilled, without the need to reposition any other element of the set-up. *Data Acquisition & Analysis:* Images were acquired using a 3D fast-spoiled gradient-echo pulse sequence (TE/TR = 0.99/3.02 ms, flip angle = 16^0, voxel size = 0.9x0.9x5 mm, 3.3 s temporal resolution, 160 dynamic acquisitions). The total duration of the protocol was approximately 9 mins. All sets of data were acquired at 1.5T (MAGNETOM Aera, Siemens) with the phantom placed in a dedicated support within the head coil to ensure position stability and reproducibility. Images were analysed using an in-house software package [3]. The evolution of CA concentration with time was calculated for two ROIs which encompassed the central straight portion of the input and output tubes, respectively. *Assessment of system linearity:* Three datasets were acquired using the standardised injection protocol, but with three different concentrations of the CA injection solution: (A) dilution factor = 1.0, [Gd] = 4.68 mM; (B) dilution factor = 0.5, [Gd] = 2.34 mM; (C) dilution factor = 0.25, [Gd] = 1.17 mM. The peak CA concentration, area under the curve (AUC) and full width at half maximum (FWHM) were extracted from the input and output CA uptake curves. *Investigation of system response:* Seven datasets were acquired with a modified injection protocol, altering the final injection rate [iii] with an adjusted final volume to maintain the total protocol duration: (a) 0.04 mL/s (40 mL); (b) 0.05 mL/s (25 mL); (c) 0.08 mL/s (40 mL); (d) 0.10 mL/s (50 mL); (e) 0.13 mL/s (63 mL); (f) 0.15 mL/s (70 mL); (g) 0.20 mL/s (77 mL). The onset time and full width at half maximum (FWHM) were extracted from the CA uptake curves. Power functions were fitted to the data and the fit assessed *via* the coefficient of determination, R^2.

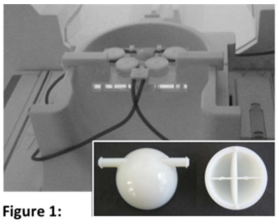

Figure 1: DCE-MRI test object set up within head coil. ***Inset:*** Four compartments within the test object.

Results & Discussion:

Assessment of system linearity: Figure 2 displays the input and output CA uptake curves resulting from the different concentrations of CA injection solution, showing clearly the reduction in curve amplitude with each successive dilution. Figure 3 plots the AUC and peak CA concentration for each ROI against the dilution factor, and confirms the linear behaviour. FWHM measurements remained approximately constant with each dilution, with coefficients of variation measured at 8.4% and 5.2% for the input and output CA uptake curves, respectively. *Investigation of system response:* Figure 4 displays the CA uptake curves obtained for the input and output ROIs at final injection rates of 0.08 mL/s and 0.1 mL/s, demonstrating the effect of final injection rate on CA uptake curve shape. Figure 5 displays the relationship between the final flush rate, signal onset and FWHM parameters obtained from the input and output CA uptake curves for datasets *a-g*, with fitted functions and associated R^2 values. Coefficients of determination, R^2, for fitted signal onset data were at 0.97 and 1.00 for input and output ROIs, respectively. For fitted FWHM data, calculated R^2 values were 0.95 and 0.98 for input and output ROIs, respectively.

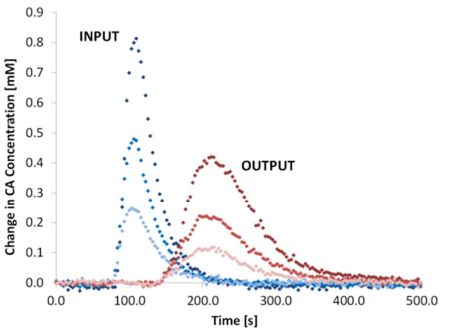

Figure 2: Input (*blue*) and output (*red*) CA uptake curves arising from dilution of the standard CA injection protocol. Dark to light shades denote highest to lowest dilution factors, A-C, respectively.

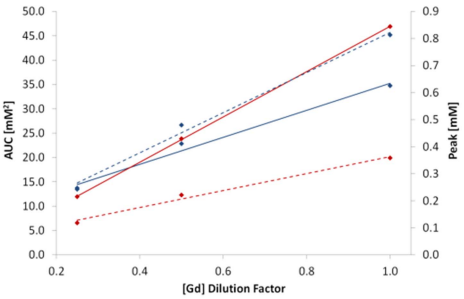

Figure 3: Linear relationships between dilution factor, area under the CA uptake curve (AUC) *(solid lines)* and peak change in CA concentration *(dashed lines)* for input *(blue)* and output *(red)* CA uptake curves.

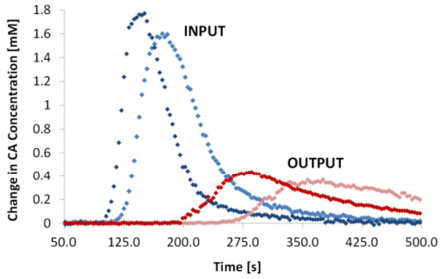

Figure 4: Input (*blue*) and output (*red*) CA uptake curves arising from modification of final velocity [iii]. Light and dark shades denote final velocities of 0.08 mL/s (c) and 1.0 mL/s (d), respectively.

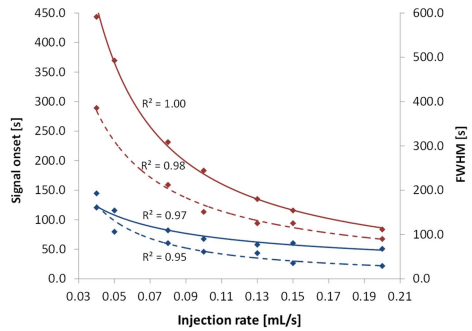

Figure 5: Signal onset (*solid lines*) and FWHM (*dashed lines*) derived from the input (*blue*) and output (*red*) CA uptake curves for datasets a-g with associated power functions fitted to the data.

Conclusion:

This work has established the linear behaviour of this novel test object: alteration of input parameters can produce predictable variations in CA uptake curve shape. A reproducible and tuneable reference dynamic enhancement curve is a valuable QA tool for DCE-MRI protocols, and can be employed in the future to investigate the effect of MR sequence alterations on the measured CA uptake curve shape.

References: [1] Driscoll B, *et al.*; *Med Phys* 2011; 38: 4866-4880; [2] Sanchez-Casas H, *et al.*; *Proc Intl Soc Mag Reson Med* 2014; 22:4850; [3] **[3]** d'Arcy JA, *et al.*; *Radiographics* 2006; 26(2):621-632.

Acknowledgements: CRUK & EPSRC support to the Cancer Imaging Centre in association with MRC & Dept. of Health, NHS funding to the NIHR Biomedicine Research Centre & Clinical Research Facility in Imaging, an NIHR Fellowship (AEWL), NIHR/HEE Fellowship (MB), & EPSRC Vacation Bursary (LS). MOL is an NIHR Senior Investigator.