A novel and affordable DCE-MRI phantom: experimental setup and assessment of reproducibility

Hector Sanchez Casas[1], Araminta E. W. Ledger[1], Craig Cummings[1], Maria A. Schmidt[1], Martin O. Leach[1], and Marco Borri[1]
[1]*CR-UK and EPSRC Cancer Imaging Centre, Institute of Cancer Research and Royal Marsden, Sutton, Surrey, United Kingdom*

Introduction

DCE-MRI has an established role as both a diagnostic and research tool, and can be performed with high temporal resolution, enabling pharmacokinetic modelling, or with an emphasis on spatial resolution. For the latter a semi-quantitative analysis is often employed to classify the contrast agent (CA) uptake curves into different types for diagnostic purposes. However the CA uptake curves, in examinations such as breast DCE-MRI, are known to present variations associated with different MRI systems and with the wide range of sequence parameters involved [1]. It is therefore important to evaluate and standardise DCE-MRI protocols; prospective quality assurance (QA) is often employed to assess the dynamic range over a range of T1 values, but this does not provide information on the protocol's ability to measure the temporal evolution of enhancement. Recent developments have devised complex dynamic test objects for DCE-MRI, but these are expensive and require dedicated physiological flow pumps [2], which are impractical for routine QA in the majority of centres. This work presents a novel DCE-MRI test object of simple and affordable design, which can create reproducible dynamic enhancement curves employing commonly available automated CA injectors.

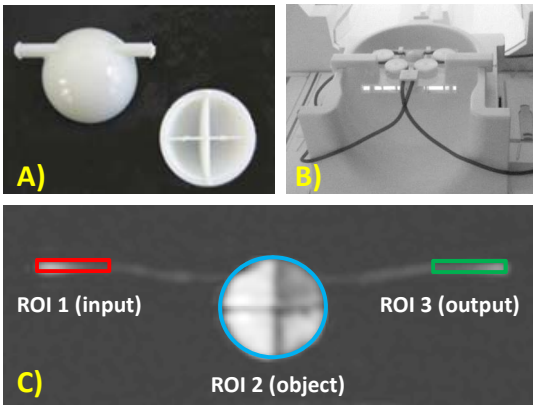

Figure 1. A) Internal (four chambers) and external structure of the test object; B) experimental setup (head coil), C) ROIs employed in the analysis.

Materials and Methods

Experimental Setup: A 4 cm internal diameter (ID) sphere with four interconnected chambers and inlet and outlet openings (Fig. 1a) was manufactured with an Eden350 3D printer (Objet Geometries Ltd) and Verowhite material (Plus FullCure 835). The object was connected with airline tubing (3 mm ID) to an automated MR injector system (Spectris Solaris EP, MEDRAD UK Ltd). The flush syringe (115 ml) was filled with water and the CA syringe (65 ml) with Gadolinium-based CA in water solution (Dotarem, Guerbet, [Gd] = 0.005 M). After filling all the circuit with water and removing air, the injector was employed to control the water flow and the CA injection. The test object was placed in a dedicated support (Fig. 1b), which ensured positioning stability and reproducibility.

Data Acquisition: Images were acquired at high spatial and temporal resolution, using a transaxial 3D fast-spoiled gradient-echo pulse sequence (TE/TR = 1.16/3.1 ms, flip angle = 18°, voxel size = 0.9×0.9×5 mm, 3.3 s temporal resolution, 160 dynamic acquisitions). The total duration of the sequence (approximately 9 minutes) was compatible with the length of clinical DCE-MRI studies. Three sets of data were acquired using different 1.5T scanners and receiver coils: Scanner 1 (MAGNETOM Aera, Siemens AG, Erlangen, Germany), head coil and Sentinelle breast coil (Hologic UK Ltd); Scanner 2 (MAGNETOM Avanto, Siemens AG, Erlangen, Germany), head coil. Each set of data contained 4 consecutive dynamic scans. For each scan the following injection protocol was adopted (approximately 9:30 minutes): 8 ml of water at 0.15 ml/s, 2 ml of CA at 0.5 ml/s and 75 ml of water at 0.15 ml/s. This produced laminar flow in the 3 mm ID tube. After each scan only the flush syringe was refilled, without the need for repositioning any other element of the setup.

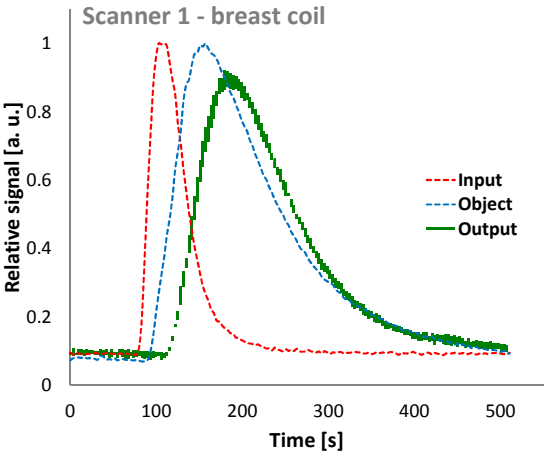

Figure 2. Average scaled dynamic curves of the input, object and output ROIs for the breast coil experiment, Scanner 1. For the output curve, the variability (average ± standard deviation) of each point is shown.

%SD	Scanner 1 – breast coil	Scanner 1 – head coil	Scanner 2 – head coil
Baseline	2.11	2.34	1.11
Peak	2.92	3.96	0.96
Final point	5.14	4.11	3.12
Maximum	8.42	9.13	6.02

Table 1. Relative standard deviation values (%SD) for the output curves in the three experiments.

Data Analysis: Images were analysed using the software package MRIW (Institute of Cancer Research, UK) [3]. Three different ROIs (Fig. 1c) were employed, encompassing the central slice through the object (1024 voxels) and the central straight portion of the input and output tubes (128 voxels), avoiding voxels with partial volume effect. For each ROI a dynamic enhancement curve, plotting the evolution of the signal with time, was extracted; the curves were scaled using the peak value of the corresponding input curve. Variability within a set of data was evaluated by calculating, for each point of the curve, the average and the percentage standard deviation (%SD) of the 4 measurements. The following values are reported: %SD of the baseline, defined as the portion of the curve prior to any enhancement; %SD of the peak; %SD of the final point; maximum %SD along the curve, as an overall index of reproducibility.

Results

We designed a reproducible experimental setup, requiring 30 minutes of preparation, which was considered feasible within the scanner time allocated for QA. Fig. 2 shows, as an example, the average dynamic curves obtained using the breast coil (Scanner 1); for the output curve, the variability range (average ± standard deviation) for each point of the curve is shown. The object mixes the CA, and acts as a transfer function (blue) between the input (red) and the output curve (green). Scaling the object and output curves with the peak value of the input curve (maximum %SD of the input peak: 8.43%) was used to account for any variation in injection or scanner scaling adjustments between different experiments. The output curves were characterized by good signal-to-noise ratio (SNR), and displayed a shape consistent with rapid CA uptake and wash-out, a behaviour typically associated with malignant tissue. Reproducibility was assessed on the scaled output curves: overall, relevant portions of the curve were reproducible within 5% variation, whilst the maximum variation over the whole curve did not exceed 10% (Table 1).

Discussion and Conclusions

We have designed a novel test object with a reproducible dynamic output, and have described a straightforward experimental setup which can be implemented with affordable components and MRI equipment accessible in most centres. The use of the automated MR injector system allowed precise flow control and resulted in a standardized injection and transit of CA to give reproducible output curves. Although the employed flow velocities have no physiological relevance, the output signal can be used to simulate the shape of malignant enhancement curves normally obtained in a clinical setting. A reproducible reference dynamic enhancement curve is a valuable tool in routine QA, and can be employed to investigate the effect of MR sequence alterations on curve shape. Future work will include optimization of flow parameters to provide curves of different shape and use of the object to optimise clinical DCE-MRI protocols.

Acknowledgement: CRUK and EPSRC Cancer Imaging Centre in association with the MRC and Department of Health (England) grant C1060/A10334, also NHS funding to the NIHR Biomedical Research Centre and to the NIHR Clinical Research Facility, and the support received from the Institute of Physics (IOP) through the scheme "IOP Top 40 Work placements".

References: **[1]** Sanaz J et al., AJR, (2009) Sep; 193(3):832-839. **[2]** Holdsworth DW et al, Med. & Biol. Eng. & Comput, 1991, 29:565-570. **[3]** d'Arcy JA et al, Radiographics (2006) Mar-Apr;26(2):621-32.