Performing Dynamic Contrast-Enhanced MRI quality assurance for multi-centre trials using a multi-compartment phantom with physiological T1s

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Introduction: Dynamic Contrast Enhanced (DCE-MRI) imaging is widely incorporated into clinical trials, but the rarity of some pathologies, such as paediatric cancer, necessitate the involvement of multiple centres to perform such trials. Variations in MR scanner field strengths, hardware, and imaging sequences mean that quality assurance is a necessary and important part of multicenter trial design and execution. We present data from a phantom containing a range of physiological T_1s [1], suitable for use in QA and development of DCE MRI protocols [2]. The phantom allows a consistent temperature to be achieved, removing a significant source of T_1 variability [3], and can be used to derive comparative metrics for different acquisition protocols across different vendor platforms. **Target Audience:** Researchers and clinical scientists involved in multicenter studies that include DCE-MRI as part of a functional imaging protocol.

Method:

Phantom Construction and Preparation: Seven vials containing varying concentrations of polyvinylpyrrolidone (PVP) in water from the same heat-stabilised stock solution were prepared, degassed, sealed, and secured inside a perspex cylinder (**Figure 1**). PVP concentrations were chosen to give T_1 range 500 – 1500 ms. Prior to scanning (>1 hour) the cylinder was packed with ice and ice water. Immediately prior to scanning, further ice was added and the temperature (0°C) was verified before sealing the phantom ready for use.

MR Imaging: Example image data were acquired on a 1.5T Magnetom Avanto (Siemens AG, Healthcare, Erlangen, Germany) using standard clinical body array coil. DCE sequence was a 3D GRE with the following parameters: TR 3 ms, TE 0.91 ms, FoV 350x262.5 mm, matrix 128x96, in-plane resolution 2.7 x 2.7 mm^2, 14 coronal slices of 5mm, partial Fourier 7/8, iPAT factor 2, bandwidth 650 Hz/Px. Reference (NSA 10) and dynamic (NSA 1, 80 acquisitions) scans were acquired with a selection of flip angles (2 and 3° reference; 11 and 14° dynamic). This DCE protocol was repeated at a second site with the same model of scanner, object preparation, and imaging parameters except: TR 3.19ms, TE 1.01ms.

Analysis: Combinations of reference and dynamic data were used in the variable flip angle method for T_1 estimation, the dynamic data were used to derive experimentally derived T_1 noise factors (NF_{T1}, Eq. 1) and T_1 SNR (Eq. 2) for each image pixel, where σ_{T1} and σ_S are the standard deviations of T_1 and the signal respectively, S_0 is the initial signal intensity, and T_S is the total scan time [4, 5]. The stability of DCE-MRI signal was evaluated using autocorrelation both within the PVP gels, and in the ice-water main compartment. Taken together these provide useful quality assurance data and a number of useful metrics to optimize and evaluate DCE-MRI protocol performance. T_1 noise factors between two sites were compared for correlation as an assessment of imaging protocol equivalency.

Eq.1:

$$NF_{T_1} = \frac{\frac{\sigma_{T_1}}{T_1}}{\frac{\sigma_S}{S_0}}$$

Eq. 2:

$$SNR_{T_1} = \frac{T_1}{\sigma_{T_1}\sqrt{T_S}}$$

Results: The phantom preformed as expected, providing high-quality images suitable for QA measurements. ROIs placed within the PVP gels demonstrate excellent stability and autocorrelation, whereas it is possible to detect events (motion/melting of ice) in the main ice-water compartment (**Figure 2**). **Figure 3** (left) shows the dependence of T_1 noise factor on T_1, with much worse noise factors being observed for higher T_1 regions. Using this metric, it is also possible to compare the noise factors obtained for T_1s of interest using different combinations of flip angles, and to map the variation of B_1 across the phantom. Comparison of NF_{T1} across ROIs from protocols between imaging sites gave an excellent correlation (**Figure 3**, right; $R^2 = 0.9955$).

Discussion: The phantom exhibits excellent stability of T_1 across the length of DCE-MRI protocols, providing a stable physiological range of T_1s at a known and consistent temperature that can be reproduced for DCE-MRI protocol QA. Derivation of T_1 SNR and noise factors allows quantitative comparison of DCE protocols both within and between imaging centres. This test object has undergone extensive testing for the QA evaluation of DWI protocols, and we have now demonstrated its suitability for evaluating DCE-MRI protocols in multi-centre trials.

Figure 1: Phantom construction with PVP gels (left), and calculated T_1 map (right) showing ROI placement.

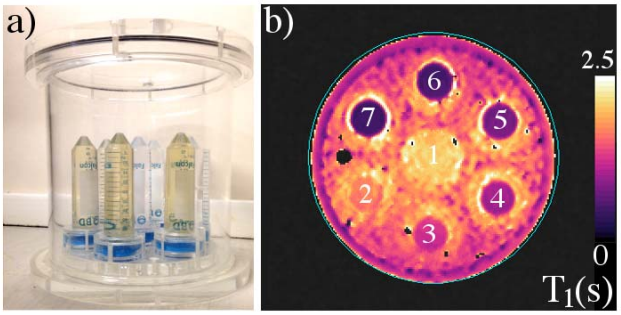


Figure 2: Autocorrelation for single voxel within PVP gel (top) and melting ice (bottom), ROIs shown on left, showing the stability and sensitivity of measurements across the DCE protocol.

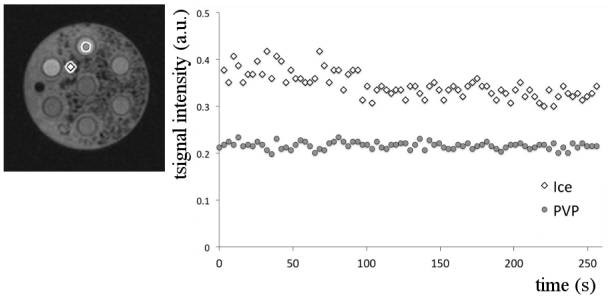
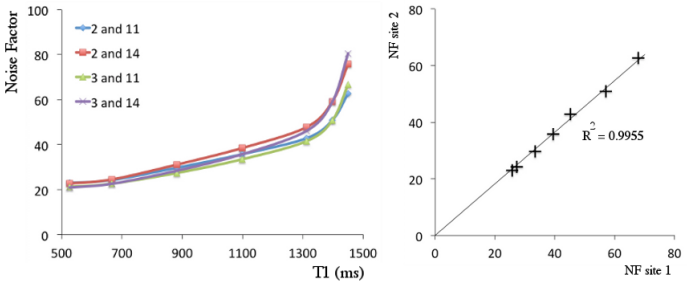


Figure 3: Noise factors against (true) T1 for varying combinations of flip angles (left), and comparison of noise factors between sites using comparable protocol shows excellent correlation (right).



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