

Improved T1 quantification using post-Gd contrast variable flip angle data

K. Miyazaki¹, J. A. d'Arcey¹, M. R. Orton¹, D-M. Koh², D. J. Collins¹, and M. O. Leach¹

¹CR-UK and EPSRC Cancer Imaging Centre, The Institute of Cancer Research and Royal Marsden Hospital, Sutton, Surrey, United Kingdom, ²Department of Radiology, Royal Marsden NHS Foundation Trust, Sutton, Surrey, United Kingdom

Introduction: In dynamic contrast-enhanced (DCE-) MRI studies, it is necessary to obtain estimates of initial (i.e. native) and dynamic T1 values in order to quantify contrast agent concentrations, [CA]. The variable flip angle (VFA) method [1], which employs spoiled gradient echo data acquired using at least two different flip angles, is a T1 and M₀ (a variable including the proton density, gain factor and echo term) estimation method that is commonly employed in DCE-MRI studies. The optimal choice of flip angles depends on the repetition time and the range of T1 values present in the imaging sample [2,3]. Flip angle optimisation in DCE-MRI studies is a challenge because the observed T1 range is large, especially in blood, which has a large peak [CA]. Furthermore, the choice of flip angle for the dynamic acquisition needs to ensure that signal linearity is maintained over a range of [CA]s for different initial T1s. Flip angle optimisations have shown that the larger the maximum T1 in the range, the smaller the optimal flip angles are [2,3]. For greater signal linearity with [CA], however, a larger dynamic flip angle is desirable. When designing a DCE-MRI protocol, the choice of flip angles needs to reflect a trade-off between the two requirements. At the end of the dynamic study, maximum T1 in the range is shortened (relative to pre-contrast) as a result of CA uptake and the signal-to-noise ratio is improved [4]. In theory, therefore, it would be possible to obtain relatively precise T1 estimates using the VFA data obtained at the end of the DCE-MRI study (i.e. final T1), and also M₀ estimates. The estimate can be propagated backward through the dynamic data to generate dynamic T1 curves, thus, enabling an estimation of the initial T1. In this study, we compared initial T1 values estimated using the described, 'post-Gd converter', method with those estimated using the normal method.

Materials and methods: DCE-MRI was performed on a 1.5 T Siemens Avanto scanner in six paediatric patients (3 with intra-cranial tumours and 3 with extra-cranial tumours). 3D VIBE sequences with the following sequence parameters were employed: TR/TE = 3.0/1.0 ms, 14 partitions, 5 mm thick, matrix size = 256x256 (interpolated), flip angle/NSA = 3°/8 (static) and 16°/1 (dynamic). 80 dynamic images were acquired over 4 mins (temporal resolution = 3 s). A single dose of Gd-DTPA was injected followed by 10 ml of saline. Patients were scanned twice within 48 hrs to assess the reproducibility of the measurements. For every dataset, two sets of initial T1s were estimated using the normal VFA method and the post-Gd converter method. With the post-Gd converter method, the final T1 and M₀ are calculated using the average of the last three dynamic data sets of the dynamic series and the static, 3° data acquired at the end of the dynamic study using the conventional algorithms [1]. Since M₀ should stay constant, the dynamic T1 can be calculated using the following expression: $T1(t) = TR / \ln\left[\frac{S(t)/\tan(\theta) - M_0}{S(t)/\sin(\theta) - M_0}\right]$ where S(t) is the dynamic signal intensity and θ is the flip angle of the dynamic acquisition. The initial T1 estimate obtained using the post-converter method is the T1 at t = 0. Regions-of-interest (ROIs) were drawn around the lesions on the central partition. In one patient, two separate lesion ROIs were drawn. Bland-Altman reproducibility values were calculated using the median values of the ROI data. ROIs were also drawn along the descending aorta in the three patients with extra-cranial tumours. Summary statistics were calculated for each ROI and averaged.

Results and discussion: Initial T1 maps calculated using the two different methods are shown in figure 1 for two example patient cases. Clearer definitions, both between and within different regions, are evident in the post-Gd converter initial T1 maps. The histograms of initial lesion T1 values show that the normal method tended to produce relatively high values several of which are above the physiologically plausible values. The post-Gd converter initial lesion T1 values exhibit tighter T1 distributions with a shift towards lower T1 values. The Bland-Altman reproducibility co-efficients for the normal and post-Gd converter methods were 19.7% and 9.4%, respectively (figure 2). Averaged summary values (in seconds) for blood T1 calculated using the normal vs. the post-converter methods are: mean ± sd = 2.29±0.64 vs. 1.43±0.19 and median = 2.19 vs. 1.41. The post-Gd converter method resulted in blood T1 values, which are in better agreement with those published in the literature. The variance is also reduced. An example scatter plot of initial blood T1 estimates obtained using the post-converter method versus the normal method is shown in figure 3. Blood T1s estimated using the normal method span a large range between 1 and 5 s, whilst those estimated using the post-converter method range between 1 and 2 s which are physiologically more plausible.

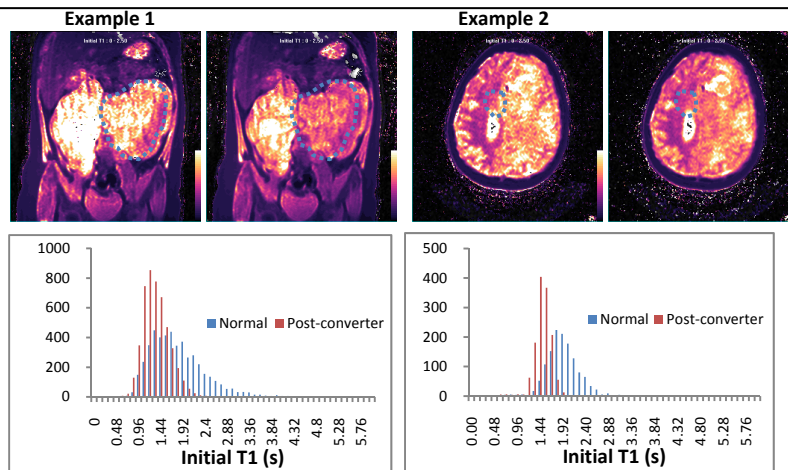


Figure 1: Examples from an extra-cranial and an intra-cranial data. Initial T1 maps obtained using the normal (left) and post-converter (right) are shown on the top row. All maps are scaled from 0.0 to 2.5 seconds using a colour scale where black denotes low and white denotes high initial T1. Histograms of initial T1 values from the lesions (indicated by blue dotted outlines) are shown in the bottom row.

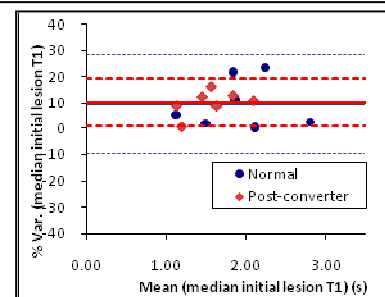


Figure 2: B-A plots for median initial lesion T1 obtained using the normal (blue) and the post-Gd converter (red). Solid lines denote the mean of the % variance and the dashed lines denote the mean +/- 1.96 SD

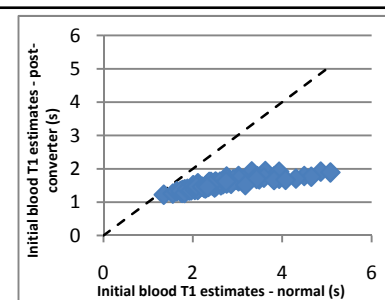


Figure 3: Scatter plot of initial blood T1 estimates obtained using the post-Gd converter method versus the normal method for one example case.

Conclusions: With the VFA method, it is important to select a set of flip angles which allow accurate and precise T1 estimations. Large T1 ranges in paediatric tumours, vessels and organs such as the spleen can make the choice of flip angles in DCE-MRI studies a challenge since these favour smaller flip angles which are not ideal for signal-[CA] linearity. This study has shown that initial T1 estimations of both lesions and blood can be improved using the VFA data acquired at the end of a DCE-MRI study where SNR is greater and long T1s are shortened as a result of CA uptake. Improvements in the quantification of blood T1s would enable more accurate vascular input function quantification. The reproducibility of initial lesion T1 estimates was also found to be better than for those obtained in the conventional manner. These enhancements in the initial T1 estimations will positively affect the quantification of DCE-MRI parameters which are investigated in several clinical settings such as in the monitoring of anti-cancer treatment effects.

References: [1] Wang HZ et al. Magn Reson Med. 5 (1987) 399-416, [2] Miyazaki K et al. In proc ISMRM (2009) 2559, [3] Schabel MC and Morrell GR. Phys Med Biol. 54 (2009) N1-N8, [4] de Bruin PW et al. In proc ISMRM (2010) 1720

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