ASSESSMENT OF ERRORS IN T1 MEASUREMENT USED FOR QUANTITATIVE DCE-MRI: CONSEQUENCES FOR PHARMACOKINETIC MODELLING.

C. A. Azlan[1,2], P. Di Giovanni[1], T. S. Ahearn[1], G. D. Waiter[1], S. I. Semple[3], F. J. Gilbert[1], and T. W. Redpath[1]

[1]Aberdeen Biomedical Imaging Centre, University of Aberdeen, Aberdeen, Scotland, United Kingdom, [2]Department of Biomedical Imaging, University of Malaya, Kuala Lumpur, Malaysia, [3]Department of Medical Physics, University of Edinburgh, Edinburgh, Scotland, United Kingdom

Introduction

T_1-weighted quantitative dynamic contrast-enhanced (DCE)-MRI is a useful imaging technique in the diagnosis of breast cancer. Using this technique, several pharmacokinetic parameters in the tissue of interest e.g. volume transfer constant of contrast agent (K^{trans}), leakage space (v_e) and the rate constant (K_{ep}) can be estimated [1]. To accurately measure the pharmacokinetic parameters in a tumour a pre-contrast T_1 measurement is required. Typically, the T_1 values are measured using a rapid 3D pulse sequence e.g. FLASH with multiple flip angles [2]. Using this sequence the signal intensity (S) produced is given by:

$$S = S_0 \cdot \frac{(1-\exp(-TR/T_1))\cdot \sin\alpha \cdot \exp(-TE/T_2^*)}{1-\cos\alpha\cdot\exp(-TR/T_1)} \qquad \text{Eq. 1}$$

where S_0 is the maximum possible signal obtainable from the system, TR is repetition time and α is the flip angle. T_1 is measured by fitting Eq. 1 to a plot of signal intensity versus flip angle for at least three flip angles (as there are 2 unknowns). For clinical applications of dynamic 3D imaging, a fast imaging approach is crucial, hence a very short TR is normally used. Any error in the calculation of T_1 in the protocol will have a direct consequence of the error in pharmacokinetic parameters. The aim of this study is to assess the errors in T_1 measurement using 3D FLASH sequence with a short TR as used for quantitative DCE-MRI.

Materials and Methods

T_1-weighted images of gel phantoms were acquired using a 3D T1-FFE multiple flip angle sequence with 2 different TRs (TR= 10ms and 110ms, TE= 2.3ms, and α= 16, 23, 35, 40 and 54°) using a Philips Achieva 3T scanner and a quadrature head coil (Philips Medical Systems, Best, the Netherlands). The signal intensities of the slice at the centre of each phantom were then measured using proprietary software. The T_1 values for the gel phantoms were calculated by fitting Eq. 1 to signal intensity versus flip angle using a Levenberg-Marquardt algorithm. We assume that T_2* is very large compared to the TE. For comparison, T_1 measurements were made using an inversion recovery (IR) approach (TR= 5500ms, TE= 20ms, TI= 50, 100, 300, 600 and 1100ms). This technique is used to give the reference measure. It is not used in DCE-MRI as it is significantly more time consuming than the multiple flip angle approach. Here the T_1s were estimated by fitting the signal intensities of each phantom versus inversion time (TI) to the following equation:

$$S = S_0(1-2\cdot\exp(-\frac{TI}{T_1})) \qquad \text{Eq. 2}$$

All curve fitting and T_1 estimations were performed using SigmaPlot (Systat Software Inc., San Jose, CA, USA).

Results

Fig 1. shows the signal intensity versus flip angle for each phantom and the resulting fitted curve of Eq 1. when a short TR is used. A plot of T_1 values measured using TFE versus IR approach is shown in Fig 2. It can be seen that the measurement of T_1 using long TR gives results very similar to those with the IR approach, whereas the short TR measurements can result in errors in T_1 of more than 100%. These errors increase with increasing T_1.

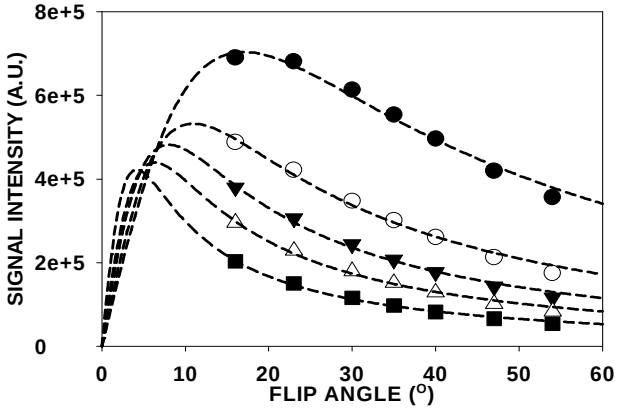

Fig. 1 Signal intensity versus flip angles for five phantoms of different T_1 values acquired using FLASH sequence with TR=10ms. The fitted lines represent Eq 1.

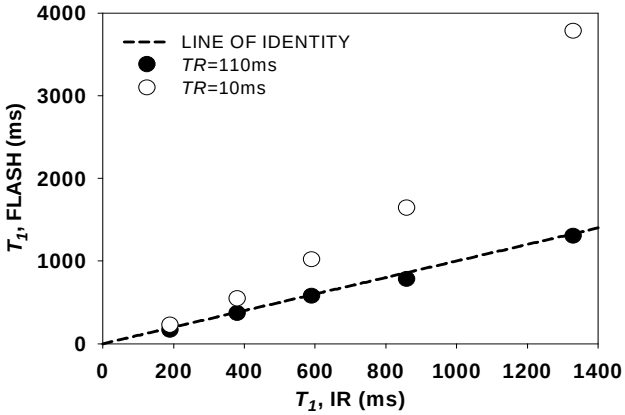

Fig. 2 A plot of T_1 values obtained using of multiple flip angle approach versus the reference inversion recovery (IR) approach when a short and long TR is used.

Discussion

Clinical quantitative DCE-MRI requires a rapid FLASH sequence approach to be used. To minimise the scanning time, a very short TR is preferable. However, this approach will increase the errors of the T_1 values measured. These errors will directly affect the accuracy in the fitted pharmacokinetic parameters. From our computer simulation, for ductal tissue (T_1=1300ms [3] and nominal K^{trans}/ v_e= 0.5min^{-1}/ 0.5), an error in pre contrast T_1 of 100% will reduce K^{trans} and v_e to about 50% of the nominal values. The errors in K^{trans} and v_e increase with error in T_1.

The source of these errors may be the incomplete RF spoiling of the transverse magnetisation during the scanning. For complete spoiling, the transverse relaxation must be destroyed before the next RF pulse.

In conclusion, quality assurance procedures using T_1 phantoms is crucial to correct the T_1 values measured using a very short TR multiple flip angle FLASH sequence. The T_1 values should be calibrated with known T_1 values measured using a reference technique before values could be reliably implemented to estimate pharmacokinetic parameters.

References

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