# Breast tumour DCE-MRI in presence of B1 inhomogeneity, effect on $K^{trans}/v_e$ using T1-weighted FLASH

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## INTRODUCTION

Quantitative dynamic contrast enhanced MRI (DCE-MRI) of the breast is becoming more common at high field (>1.5T). Following the infusion of a gadolinium based contrast agent pharmacokinetic models are fitted to the tumours' signal enhancement curve. A major drawback to high field MRI is the increased B0 and B1 inhomogeneity. These cause artefacts that can significantly compromise the reliability of the MR signal particularly for T1-weighted FLASH sequence. It is well known that breast imaging at 3T is difficult due to the standing-wave or RF inhomogeneity effect[1-2]. This gives rise to errors in the effective flip angle and hence can manifest as variation in signal intensity (per unit spin density) across the field of view. This variability in signal has the potential to compromise the accuracy in quantification of pharmacokinetic parameters. In this study the RF inhomogeneity in breast imaging at 3T is measured and the effects of RF inhomogeneity on pharmacokinetic parameters $K^{trans}$ and $v_e$[3] is simulated and evaluated.

## MATERIALS AND METHODS

On a 3T whole-body scanner (Philips Achieva X Series, Best, The Netherlands) and a seven channel breast coil B1 maps of normal volunteers were produced using the Yarnykh method[4]. Enhancement curves were simulated using Tofts' model and 9 combinations of $K^{trans}$ and $v_e$ ($K^{trans}$ = 0.5, 1.2, 2.5 min$^{-1}$ and $v_e$ = 0.3, 0.5, 0.7)[5]. Typical DCE-MRI acquisition parameters were incorporated into the simulation by assuming acquisition with a RF spoiled FLASH pulse sequence (TR = 8.4 ms, TE = 4.2ms) with an image acquired every 10 seconds for 6 min and 30 seconds. The pre-contrast tissue T1 was assumed to be 1.4s (approximately equal to that of glandular breast tissue at 3T[6]). B1 inhomogeneity effects were simulated by producing signal enhancement curves for an incorrect flip angle and fitting this data to the Tofts' model while assuming a nominal flip angle. Here a nominal flip angle of 35° was assumed and errors up to +/-55% were investigated, such that data was generated for flip angle ranging from 16 º to 54º. The $K^{trans}$ and $v_e$ fitting procedure is based on the Levenberg-Marquardt algorithm implemented in IDL (Research Systems, Inc, Boulder, Colorado). Different starting values for $K^{trans}$ and $v_e$ have been used in the fitting routine in a way to avoid falling in local minima[7].

## RESULTS

From the B1 mapping, errors up to 50% of the nominal flip angle were observed when imaging was performed axially. There was a marked left-right difference and the flip angle was less than expected. Figures 1 and 2 show plots of flip angle error (in respect to the nominal 35° degrees) versus $K^{trans}$ and $v_e$ error (respectively) obtained with the software simulations. Here error is calculated as the difference between fitted values and nominal values of $K^{trans}$ and $v_e$. Figure 1 shows that $K^{trans}$ error increases with flip angle error. Also, that when the applied flip angle is lower than the nominal angle, $K^{trans}$ is underestimated while it is less severely overestimated when the flip angle is higher than the nominal. As $K^{trans}$ increases there is a greater sensitivity to B1 inhomogeneity. $K^{trans}$ can drop by up to 30% when its starting value is as high as 2.5 min$^{-1}$ ($v_e$ = 0.7) and there is an underestimation of the flip angle equal to 55% of its nominal value. On the other hand if the flip angle is overestimated at 55% of its nominal value $K^{trans}$ becomes overestimated up to 7% of its expected value. As $v_e$ increases the sensitivity to B1 inhomogeneity increases. As in the case of $K^{trans}$, $v_e$ is underestimated when the applied flip angle is lower than the nominal one and is less severely overestimated when the applied flip angle is higher than the nominal one. Different from $K^{trans}$, $v_e$ shows the same increase/decrease independent of the associated $K^{trans}$. When $v_e$ is as high as 0.7 and the flip angle is underestimated up to 55% of its original value $v_e$ is underestimated by 34% of its expected value. When the flip angle is 55% over its nominal value $v_e$ is overestimated by 8% of its expected value. Figure 3 shows how the summed squared residuals of the fit reduce when the flip angle error approaches zero. The miss-fit is more severe at lower flip angles, with higher values of $v_e$ and $K^{trans}$.

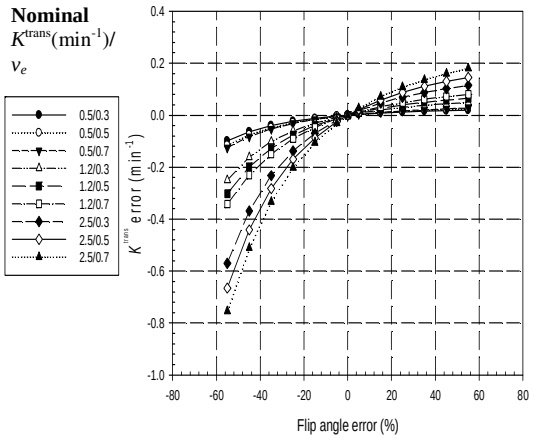


Figure 1. Flip angle error versus $K^{trans}$ error

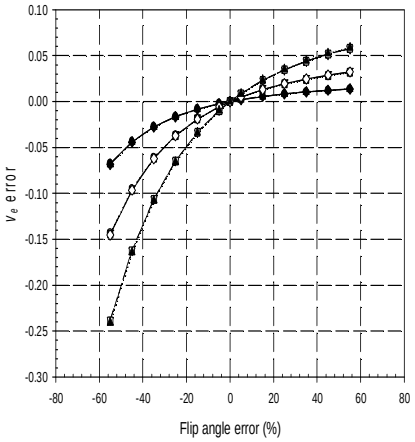


Figure 2. Flip angle error versus $v_e$ error

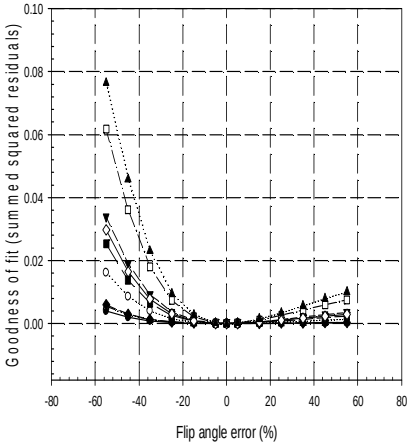


Figure 3. Flip angle error versus goodness of fit

## DISCUSSION

We have shown that the greater the values of $K^{trans}/v_e$ the greater sensitivity to B1 inhomogeneity. The extent of the errors is partially due to miss-fitting the curve at incorrect flip angles. The magnitude of this depends primarily on the value of $v_e$, secondary on $K^{trans}$. Giving that at high field MRI the effective flip angle is generally lower and not higher than the nominal one we can observe maximum underestimation errors up to 30% for $K^{trans}$ and 34% for $v_e$; errors of this magnitude have clearly a strong impact on any quantitative measure of the tumour physiology and a correction for this is needed. The B1 inhomogeneity effect can be corrected in two ways, either by working on a different T1-weighted pulse sequence less affected by RF irregularities or by post-processing the data. This last method implies the acquisition of a B1 map over the imaged area which can then be used as a look-up table for correcting flip angle errors; the main drawback of this approach is that it would increase the overall duration and complexity of the clinical scan.

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## REFERENCES

*1.* Kuhl CK et. al. *Radiology* 2007; **244**(3):929-30.
*2.* Dietrich O et al. *Eur. J. Radiol.* 2008; **65**(1):29-35.
*3.* Tofts et al. *Magn. Reson. Med.* 1991; **17**: 357-367.
*4.* Yarnykh VL. *Magn. Reson. Med.* 2007; **57**(1): 192-200.
*5.* Hayes C et al. *NMR Biomed.* 2002; **15**:154-163.
*6.* Rakow-Penner R et al. *J. Magn. Reson. Imaging* 2006; **23**(1): 87-91.
*7.* Ahearn TS et al. *Phys. Med. Biol.* 2005; **50**(9): N85-N92.