Effects of Flip Angle Variations on the Accuracy of Perfusion Parameters in DCE-MRI

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Introduction: Dynamic contrast-enhanced (DCE-) MRI has become a valuable tool in the assessment of tumors and in the evaluation of the effects of treatment. Kinetic modeling with two or three (including tumor vascular component v_p) compartments is commonly used to measure the parameter K^{trans}, a first order rate constant that describes tumor perfusion and vascular permeability. In its calculation, the flip angles used for DCE-MRI and for computing the tumor's intrinsic T_1 (if variable flip angle (VFA) technique is used), must be known. However, flip angle inaccuracies can often occur due to inhomogeneous RF fields and slice profile effects [1]. The goal of our current work is to evaluate to what extent deviations in flip angle can occur in a large FOV DCE-MRI protocol and determine how those variations affect the measurement accuracy of perfusion parameters (K^{trans}, v_e).

Methods: Actual flip angle imaging (AFI) [2] was applied in patients undergoing MRI to determine the flip angle variability throughout the imaging FOV (=40cm), using the following AFI parameters: TR1/TR2 = 6/24 ms, $\alpha_{AFI}=60^0$. Based on the range of flip angles observed in the images, potential errors in the measurement of various perfusion parameters were computed. Towards this end, the following true parameter values were used K^{trans} = 0.4 min^{-1}, v_e = 0.4, and v_p=0.02 to generate a DCE-MRI dataset. For the arterial input function, an experimentally-derived functional form based on a population-averaged input function described previously was utilized [3]. The flip angle was adjusted from the nominal angle (25°) such that it varied spatially based on the % flip angle error computed from the in vivo AFI map. Subsequently, DCE-MRI data were fit to the Tofts' model using the assumed nominal flip angle (25°) to compute the perfusion parameters. The calculations were performed in two ways: (1) Using the correct value of intrinsic tumor T_1 (=800 ms); (2) Using baseline T_1 values "measured" with the variable flip angle (VFA) technique [4]. For the latter, the flip angles used for VFA images (4°, 10°, 15°) were also spatially adjusted according to the AFI map to account for the spatial variability, while the fitting procedure to determine T_1 from these images assumed the nominal angles. For both cases, an assumed blood T_1 of 1200 ms was used as it usually done.

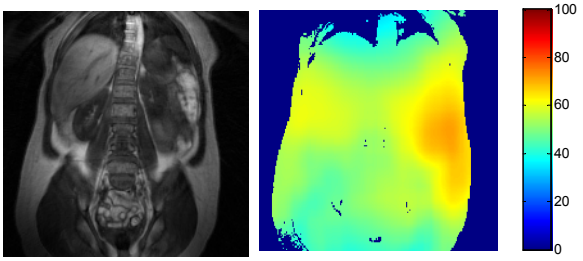

Fig. 1 (Left) Anatomic image. (Right) Flip angle map generated using AFI. The nominal flip angle was 60°. The scale at right is the flip angle in degrees.

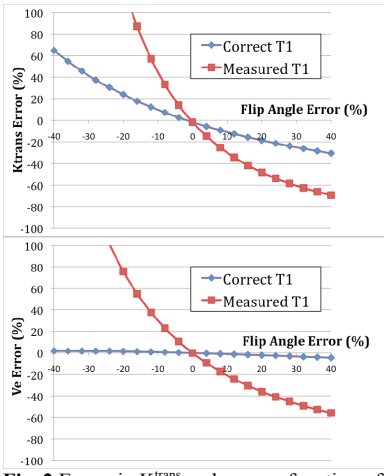

Fig. 2 Errors in K^{trans} and v_e as a function of errors in the flip angle. The nominal flip angle (which is assumed in computing the parameters) was 25°.

Results and Discussion: **Figure 1** shows a representative flip angle map of the coronal section of the chest/abdominal region in one of the subjects, showing large variations that occur throughout the body, both along superior/inferior and lateral regions of the torso. **Figure 2** shows the errors in the computed K^{trans} and v_e as a function of errors in the flip angle. The plots highlight the extent to which K^{trans} can vary depending on the flip angle. The blue curves were generated using the correct intrinsic T_1, while the red (steeper) curves were computed using baseline T_1s measured using VFA. It is apparent that the errors are substantially higher when incorrectly measured T_1s are used for the calculations. For example, a -20% error in flip angle (so that the true angle = 20° instead of the nominal 25°) results in a 24% error in K^{trans} when correct T_1 is used while yielding errors greater than 100% using the measured values. Also, with correct baseline T_1, v_e varies by less than 5% even for flip angle as large as ±40%, while the errors are much higher with measured T_1. It is also evident that negative flip angles errors (lower angle than nominal), which occur more in the inferior/superior regions of the body (**Fig. 1**), yield larger errors than larger flip angles, seen more in the lateral regions. **Figure 3** shows a K^{trans} map generated from the flip angle map in **Fig. 1**, depicting the spatially dependent errors in K^{trans}.

It should be noted that it is possible that the *changes* in perfusion parameters, e.g. following treatment, may be affected to a lesser degree than the absolute errors themselves. However, identical patient positioning between exams will then likely be an important factor to minimize errors. Imaging at higher fields is also expected to be more problematic, as finite wavelength effects will cause greater B_1 (and thus flip angle) variations throughout the body.

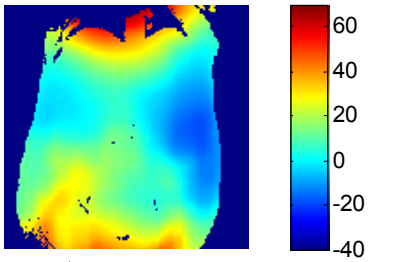

Fig. 3 K^{trans} error (%) throughout the imaging FOV if the nominal flip angle is used for its calculation. For this map, true tissue T_1 was used. The errors would have been much higher had measured values been used.

Conclusion: The current work shows that flip angle variations in the body can cause substantial errors in the perfusion measurements, and determining the actual flip angle may be critical. Such inaccuracies can easily mask true changes in tumor treatment response, or indicate effect in the absence of true response. Flip angle mapping should therefore be part of every DCE-MRI protocol, in particular when lesions are located peripherally and when large FOV is used to track multiple tumors dispersed throughout the body.

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Reference: (1) Parker et al. Magn Reson Med 2001; 45: 838-845. (2) Yarnykh et al. Magn Reson Med 2007; 57:192-200. (3) Parker et al. Magn. Reson. Med. 2006, 56:993-1000. (4) Cheng et al. Magn Reson Med 2006; 55: 566-574.