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_e) compartments is commonly used to measure the parameter K_1, 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 T1, 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_1, 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, α_1=60°. 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_1 = 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 T1 (=800 ms); (2) Using baseline T1 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 T1 from these images assumed the nominal angles. For both cases, an assumed blood T1 of 1200 ms was used as it usually done.

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_1 and v_e as a function of errors in the flip angle. The plots highlight the extent to which K_1 can vary depending on the flip angle. The blue curves were generated using the correct intrinsic T1, while the red (steeper) curves were computed using baseline T1 values “measured” using VFA. It is apparent that the errors are substantially higher when incorrectly measured T1’s 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_1 when correct T1 is used while yielding errors greater than 100% using the measured values. Also, with correct baseline T1, v_e varies by less than 5% even for flip angle as large as ±40°, while the errors are much higher with measured T1. 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_1 map generated from the flip angle map in Fig 1, depicting the spatially dependent errors in K_1.

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 B1 (and thus flip angle) variations throughout the body.

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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