A Multi-Paramter Analysis for the Optimization of Delayed Enhancement Imaging Using Known Myocardial T1 Values

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Introduction: There is a current understanding in cardiac MRI that delayed enhancement imaging is technically challenging. Not only is image quality and contrast sometimes less than optimal, but there are also many variants of the delayed enhancement sequence itself. There are many ways to optimize image quality ("Look-Locker", PSIR), with the focus concentrating on defining the optimal inversion time to null normal myocardium (TI_{null}). Other significant parameters such as flip angle and acquisition duration are often determined empirically. An additional method to analyze trends in sequence optimization is to utilize serial T_1 time courses post-contrast administration (1,2) in conjunction with a computational model of the spoiled fast gradient-echo technique (FLASH), since this sequence is both the most common type of sequence used in delayed enhancement imaging and is well-described in the literature (3).

Purpose: The purpose is to describe the IR-FLASH sequence analytically, and to utilize known values for infarct and normal myocardium T_1 post-contrast to determine optimal signal contrast as a function of common image primary parameters (*TI* and flip angle).

Methods: In general, the T_1 of normal myocardium/infarct tissue in humans is approximately 0.36/0.26s, 0.39/0.26s, 0.41/0.28s, 0.43/0.30s at 10, 15, 20, 25 minutes post-contrast at 1.5T, respectively (1,2). These values will be used as input into the theoretical simulations of signal contrast using a segmented inversion recovery (IR) FLASH imaging sequence. This sequence has been described previously, but has been expanded here to account for lines/segment, and segment interval time (*RR*). A full picture of the magnetization response in delayed enhancement imaging also involves the added influence of previous segments and the inversion pulse delay time (*TI*). Furthermore, when the flip angle is varied at the beginning of each segment to lessen saturation effects (a common practice in segmented linear acquisitions), the model becomes a complicated expression of products and summations. This IR-FLASH simulation was implemented in an iterative fashion based on the entered sequence parameters, and to the point where magnetization was to be determined (typically $k_y = 0$). To validate the IR-FLASH expression, experiments were conducted on an array of 6 Gd-doped 50ml tubes of saline indicative of normal and infarcted myocardium post-contrast (normal T_1 = 358, 430, 535ms; infarct T_1 = 269, 240, 217ms) on a 1.5T Philips Intera scanner equipped with a head coil. The samples were imaged with 300mm^2 FOV, 256 matrix, TR/TE/flip = 4.4/2.2ms/20°, 26 lines/seg, *TI* = 100-500ms (25ms steps), and *RR* = 1700ms (2-heartbeat interval). "T_1-contrast" was defined as the *absolute difference between infarct and normal myocardium transverse magnetizations at $k_y = 0$*. Measurements were normalized and correlated with those predicted by the simulation model to confirm accuracy of the model. Following confirmation, the IR-FLASH model was simulated off-line using the T_1 values from post contrast infarct and normal myocardium. Even though any combination of parameters can be implemented, we used TR = 5.0ms, 16 lines/segment, 5 dummy excitations, 13 pulses to $k_y = 0$ (linear k-space coverage), *RR* = 1700ms, 4 segment repetition history, and a variable flip angle rise from pulse 1 to pulse 13. These values were selected to restrict imaging to a typical breath hold duration. Flip angle (α) and TI were left as variables for optimization, since these were the primary variables affecting contrast.

Results: Figure 1 shows phantom results validating the IR-FLASH model. Generally, high correlation was achieved between the imaging results and the simulation data ($r^2 > 0.90$). Figure 2 shows a T_1-contrast contour plot of α and *TI* for IR-FLASH (using the parameters above), and T_1 at 10minutes post-contrast. The dark band in the image represents a point of zero contrast between infarct and normal myocardium, as a result of assuming magnitude images. Also apparent are the optimal flip angle (α_{opt}) and inversion time (TI_{opt}). Note that TI_{opt} is different than TI_{null}. Despite the presence of optimal values for α and *TI*, it can be seen that there is a large region of maximal T_1-contrast surrounding the optimal values. This implies that there is some lee-way in *TI* and α selection to garner high T_1-contrast in delayed enhancement imaging, which effectively includes the traditional TI_{null} value. Table 1 lists optimal values for each time point studied, and shows that α_{opt} is constant over time post-contrast.

Conclusions: We have developed an IR-FLASH theoretical model that accurately predicts image contrast based on sample T_1 values and sequence parameters. Therefore, this model can be adapted to investigate contrast mechanisms using a variety of sequence permutations for sequence optimization. It has also been shown that there is a generous region of high T_1-contrast that allows a range of *TI* and α to be used in delayed enhancement imaging. Since $TI_{opt} > TI_{null}$, TI_{opt} could be adapted to null normal myocardium while providing optimal image contrast.

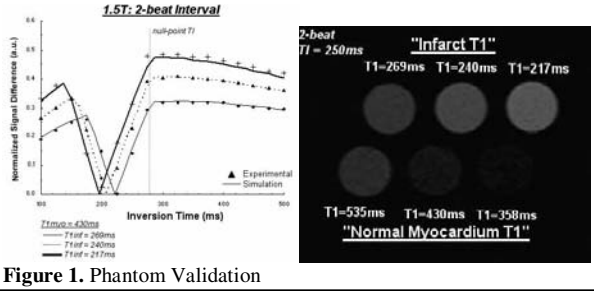

Figure 1. Phantom Validation

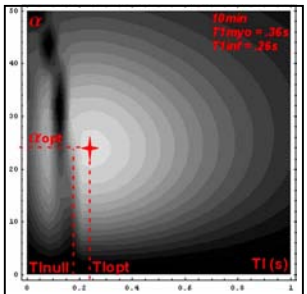

Figure 2. T1-contrast plot

Table 1. TI_{opt} and α_{opt} from simulations

Time (min)	Max T_1-contrast	α_{opt}	TI_{opt} (ms)	TI_{null}* (ms)
10	0.058	23.7	306	234
15	0.072	23.7	319	253
20	0.067	23.6	340	265
25	0.062	23.6	362	278

T_1-contrast using TInull ~4% less than TIopt.

References

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