Determination of Optimal Liver-Lesion Contrast in LOW-TIDE B-SSFP Imaging

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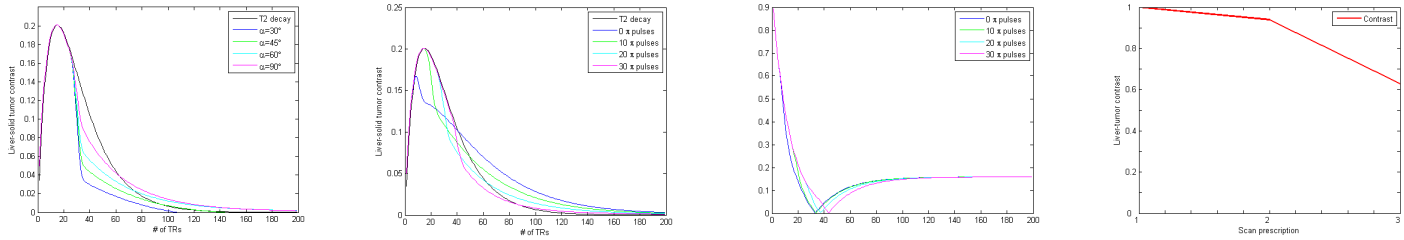
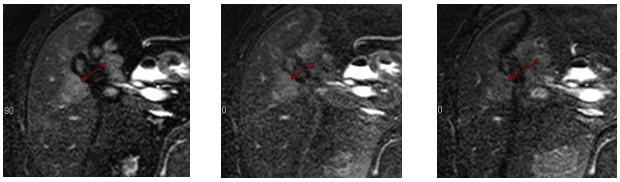
Introduction: Previously, a variation of the Transition to Driven Equilibrium (TIDE) [1] called LOW-TIDE for Linear filter-based Optimal Window TIDE [2] approach to catalyzing the steady-state signal during continuous acquisition of image data in balanced SSFP had been presented. The LOW-TIDE technique has the advantage of smaller signal fluctuations at off-resonance frequencies for relatively long T2 species. In TIDE and LOW-TIDE scans, an (α/2)-(TR/2) preparation pulse is followed by a train of π (180°) pulses. This is followed by a smooth ramp down to the final flip angle. LOW-TIDE balanced SSFP is a potential alternative to breath-held T2-weighted single-shot turbo spin-echo imaging in body or abdominal applications. The LOW-TIDE approach provides T2 weighting for the typically (T2/T1) weighted b-SSFP sequence as well as intrinsic fat suppression when done with partial Fourier phase encoding. Here we investigate contrast characteristics for optimal LOW-TIDE imaging of liver metastases. Results from patient scans are used to validate theoretical predictions.

Materials and Methods: A 4-term Blackman-Harris (B-H) window was used to calculate flip angles on the ramp down to the final flip angle. Simulations for evolution of magnetization at 1.5T were performed in Matlab® based on the algorithm in [3]. Liver T1 and T2 was assumed to be 46ms and 586ms [4] at 1.5T while T1 and T2 values for solid tumor were assumed to be 80ms and 1004ms [5], respectively. Magnetization typically follows pure T2 decay as long as the flip angle is maintained at 180°. Signal decay curves have a complex dependency on the number of π pulses and the duration of the ramp down pulses. Simulations were carried out for a range of asymptotic flip angles, # of π pulses and ramp down pulses. Behavior of spins at fat resonance (~217Hz at 1.5T) was also simulated. Adequate fat suppression dictates a limited range of effective echo times (and partial Fourier factor — PFF). Since liver-solid tumor contrast varies across k-space, a simple ramp weighting model for k-space [6] (with maximum weighting at center of k-space) can be used as a measure of effective contrast. Accordingly, contrast could be expressed as a cumulative sum: $C = \sum_{i=-M}^{N} k(i)c(i)$ where C is the total contrast (to be maximized), $k(i)$ is the k-space weighting at encoding step i and $c(i)$ is the contrast at that step obtained from the liver-solid tumor signal difference curve. On-resonance spins were analyzed although the effect of off-resonance on liver-solid tumor contrast is discussed later. The B-H preparation scheme was implemented in Philips PPE (pulse) software release 2.5.3 SP3. Four patients were scanned under an IRB approved protocol on a Philips 1.5T Achieva scanner. Three different protocols were compared to theoretical predictions. Scan parameters used were: TR=3.5ms, TE=1.75ms, α=90°, 268×200 matrix, PFF=0.70 (effective TE=133ms); preparation schemes: (a) two 180° pulses, 20 on ramp down (b) ten 180° pulses, 20 ramp down and (c) twenty 180° pulses, 20 on ramp down. Contrast was measured as a difference in the signal value in a tumor and surrounding liver tissue. Noise levels were found to be approximately constant.

Results: Figure 1 compares the contrast between liver and solid tumors as the asymptotic flip angle is varied between 30° and 90° for LOW-TIDE (with the same preparation scheme) and with contrast obtained from pure T2 decay. Repetition time was 4ms and TE=TR/2. From Figure 1, a final



flip angle of 90° provides the best contrast. Peak contrast value of ~0.2 occurs at time ~ 60ms. Figure 2 shows the contrast as the number of π pulses is varied from 0 to 30 while the ramp is kept constant at 20. However, typically fat suppression is desired and dictates (Figure 3) the effective echo time and partial Fourier factor (fat assumed 217Hz off-resonance). The required effective echo time is then much higher. For example, for the scan



resolution and parameters used here, the effective TE~38×TR which corresponds to PFF~0.7. The calculated contrast ratios are then 1.0, 0.96, 0.93 for the three cases while it is 0.97 for pure decay (normalized scale). This suggests that the number of ramp pulses be kept low. However, a rapid transition from π to the final angle can result in artifacts. Therefore, the number of ramp pulses was fixed at 20 and three different protocols (given in Methods section) were compared. Figure 4 summarizes the contrast measured between five solid tumors and surrounding liver tissue for the four patients using the three different protocols. Figure 5 shows sample images (same window/level) of a liver lesion (red arrow) obtained using the three preparation schemes (see Methods) : (a) left (b) middle and (c) right.

Discussion: There is good agreement between theoretical contrast predictions and imaging results for hepatic metastases. The need for fat suppression typically dictates use of longer effective echo times. Under such circumstances, using the fewest number of 180s and sufficient ramp down pulses (TRs) to provide a smooth transition gives the best liver-tumor contrast. The result holds for typical scan parameters and field variations found in practice.

References: [1] J. Hennig et al., *MRM.*, 48: 801-809 (2002). [2] N. Gai et al., *ISMRM*, 2007: 1642. [3] B. Hargreaves et al., MRM, 46 : 149-158 (2001). [4] C. de Bazelaire et al., *Radiology*, 2994 ; 230 :652-659. [5] M. Goldberg et al., *AJR*, 1993 ; 160 :1011-1017. [6] T. Nguyen et al., *MRM*, 2001; 46: 1037-1040.