No Inversion Double Angle Look-Locker (niDALL) for Flip Angle Mapping

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Introduction: Transmit B1 inhomogeneity is a major problem at higher field strengths. The RF wavelength decreases with increasing field strength and at 3T and above begins to approach the same scale as the human body. This leads to destructive interference and non-uniform excitation of tissue. Methods exist for correcting this non-uniformity, but mapping the B_1^+ field is a prerequisite. One method [1] makes use of the accelerated 3D Look-Locker sequence [2], a technique that requires inversion pulses. These can lead to problems with SAR, and with large B1 non-uniformities, even adiabatic inversions can be unreliable. It is possible, however, to extract the same information without the need for any inversion pulses, and we introduce this "no-inversion" Double Angle Look-Locker (niDALL) method here.

Theory: The conventional Look-Locker sequence uses an inversion pulse followed by a long train of small tip excitation / spoiled gradient echo read out pulses. Phase encoding and segmented k-space acquisition can be implemented to produce an accelerated 3D data set with images at various effective TI times along the recovery curve. The sampled recovery curve is similar to a standard inversion recovery curve, but it recovers according to a modified time constant T1*, which depends on the true flip angle α, true T1, and timing between small tip excitation pulses τ. The DALL method involves measurement of this recovery curve twice; once using a nominal small tip angle ($1\alpha_{nom}$) and then twice that nominal angle ($2\alpha_{nom}$), giving two values for T1*. These can be combined with an analytical formula [1] to find the actual flip angle present in that voxel. We introduce here an extension of the original DALL method, in which the same results can be obtained without any preparation pulses at all. If the $1\alpha_{nom}$ and $2\alpha_{nom}$ sampling trains are alternated, the signal acquired during the 1α train will decay / recover from the value determined by the magnetization at the end of previous 2α train and towards the steady state value of the 1α train, and vice versa for the signal acquired during the 2α train. After several cycles of 1α /2α, a dynamic steady state will be set up. Importantly, the decay/recovery time constants T1*(1α) and T1*(2α) can be shown to equal those obtained from the more conventional DALL method.

Methods: A whole-body 3T scanner (GE Healthcare, Waukesha, WI) using a transmit/receive quadrature birdcage head coil was used to image a small phantom (therefore demonstrating minimal B_1^+ inhomogeneity), containing $NiCl_2$ doped samples with T1s ranging from 180 ms to 3000 ms. The imaging matrix was 64x64 in-plane with 24 slices in the 3D slab. There were 128 pulses, with a repetition time of 4.4 ms, in each 1α /2α pulse train, which were segmented into 8 effective echo times (thus producing a 16-fold acceleration in the accelerated LL image acquisition). Experiments were conducted both with and without inversion prep pulses, to produce irDALL and niDALL maps, respectively. Total scantime was just under 2 min. The excitation flip angle was varied by changing the RF amplitude for the sampling pulses (i.e. without changing the inversion pulse amplitude) to achieve nominal 1alpha values ranging from 1^o to 15^o. The results were compared against a large flip angle AFI [3] method (TR1/TR2 = 30/150ms, nominal alpha =40^o, scantime = 4:40). A whole-body 7T scanner (GE Healthcare, Waukesha, WI) using a 2 channel transmit/receive quadrature birdcage head coil (Nova Medical Inc., Wilmington MA) was used to investigate the performance of the niDALL technique in the presence of a high B_1^+ non-uniformity in an 18cm diameter saline-filled sphere phantom. The imaging matrix was 64x64 in plane, with 28 slices, and 128 1α/2α pulses (α_{nom} =10^o), with a repetition time of 3 ms, were played out in each train, segmented into 8 effective echo times.

Results: Figure 1 shows the experimentally measured niDALL decay/recovery data points, as well as the resulting non-linear least square fit curves, in a sample for which T1=740 ms at 3T. The 1α (α_{nom}=8^o) curve (x symbols) recovers towards but does not reach steady state, after which the 2α decay curve (diamond symbols) starts at approximately twice the signal at which the 1α curve ended because of the double excitation angle), and relaxes towards its steady state value, ending at a value approximately twice that at which the 1α curve started with. T1*(1α) and T1*(2α) values extracted from these two fits were then combined using the DALL formula [1] to find the actual flip angle in that voxel. Using the multi-T1 phantom, the performance envelope was investigated for the niDALL technique. The AFI technique confirmed that the actual flip angle was uniform and was within 10% of the nominal. As prescribed, the niDALL technique produces actual flip angle estimates that are within 20 percent of the nominal flip angle for angles ranging from 3^o to almost 15^o independent of T1 (Fig. 2), while maintaining high α-to-σ_α ratio (ANR) in the actual flip angle maps (ANR in the range 10-40) (Fig. 3). While not shown, the performance envelope for irDALL is similar. For comparison, the AFI method at 40^o produces an ANR of 40. At 7T the B1 inhomogeneity is quite large (Fig. 4), leading to a large variation in flip angle of 8^o-16^o; despite this, the niDALL map shows minimal noise.

Discussion and Conclusion: DALL is a fast and efficient method of producing 3D maps of the flip angle, but requiring the use of inversion pulses adds to SAR and complicates the data analysis as image phase must be considered. By interleaving the 1alpha and 2alpha trains it is possible to remove the requirement for the inversion pulses entirely, and still obtain flip angle maps equivalent to inversion prepared DALL.

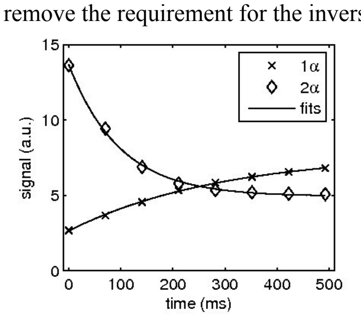

Figure 1

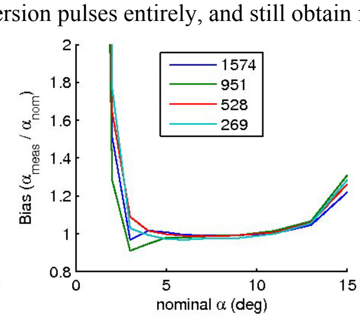

Figure 2

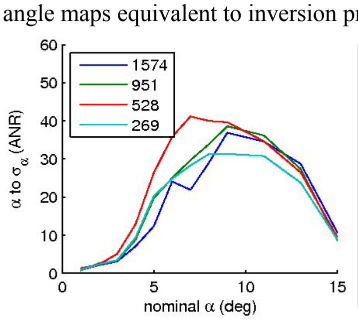

Figure 3

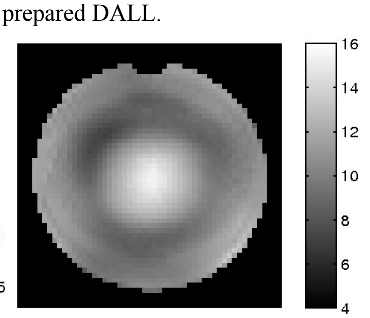

Figure 4 (α, deg)

References: [1] Wade T, Rutt B, In: Proceedings of the 16th Annual Meetings of ISMRM, Canada, 2008. p 1246. [2] Henderson, E., McKinnon, G., Lee, T-Y., Rutt, B.K., *Magn Reson Imag*, 1999; 17:1163-1171. [3] Yarnykh, V.L., *Magn Reson Imag*, 2007; 57:192–200.