Improving the inversion efficiency in regions of low γB1 for whole brain acquisitions

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Introduction: At ultrahigh fields, the heterogeneity of the radiofrequency (RF) transmit field and the larger B0 inhomogeneities present are a challenge when implementing inversion pulses for whole-brain coverage acquisitions such as used in a magnetization prepared rapid acquisition gradient echo (MPRAGE). The hyperbolic secant (HS1) adiabatic inversion radio-frequency (RF) pulse used by default in a MPRAGE acquisition often results in an incomplete inversion in regions with large B0 offsets or in regions prone to low RF power (γB_1). An HS8 adiabatic pulse can perform the same inversion at much lower peak RF power amplitudes [1], yet, theses pulses may still result in regions of poor inversion if the B1 distribution is particularly low. Recently optimization algorithms have been applied to tune adiabatic pulses to achieve good inversion efficiency at very low γB_1. The purpose of this study is to compare the inversion efficiency of a HS8 and frequency offset corrected inversion (FOCI) in a MP2RAGE [2] scan. The optimization used the genetic algorithm proposed in [3] to minimize the γB_1 required for sufficient inversion.

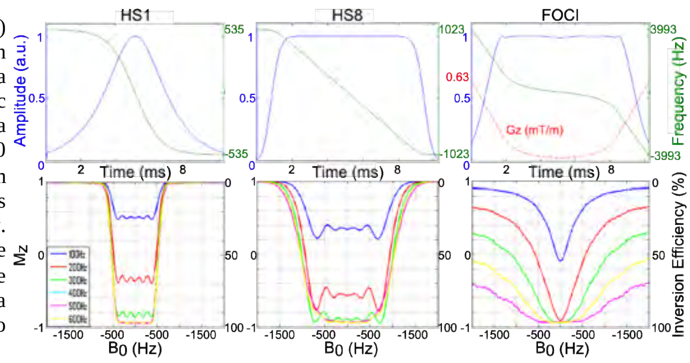

Figure 1: Magnitude envelope, frequency sweep and gradient profiles of the RF pulses with their simulated inversion profiles as a function of B0 and γB_1.

Methods & Materials: The magnitude and frequency envelopes are given in the top row of Figure 1, along with the simulated B0 profiles (bottom row). The duration of each pulse was matched to the HS1 pulse, 10.24msec. The HS8 pulse was designed with twice the bandwidth of the default HS1 pulse, and the FOCI pulse was optimized using the algorithm in [3]. To cover the whole head, the cost function in the algorithm was defined to have an ideal slice thickness of 300mm in z-direction whilst relaxing the condition to have a sharp transition band.

The three adiabatic inversion pulses were tested with a whole-brain MP2RAGE acquisition in three normal subjects (the first subject also underwent a repeat scan). The different inversion pulses were applied with a max peak γB_1 of 700Hz. Typical image parameters were: TR/TE/TI 5500ms/2.84ms/750ms Matrix 246x256x172, voxel 1x1x1mm. The two MP2RAGE images were used to provide "uniform" images that are compensated for B1 inhomogeneity and T1 maps, assuming an inversion efficiency of 98%. Regions of interest were manually identified for comparison of the actual inversion efficiency effect on the T1 values.

In addition, B0 maps were acquired using the method described in [4] (TR/TE1/TE2/ΔTE 300ms/4.08/8.16/4.08ms, Matrix 240x256, 25 slices, voxel 1x1x2mm), along with B1 maps obtained by a SA2RAGE acquisition [5] (TR/TE 2400/0.79ms, Matrix 120x128, voxel 1x1x2mm). All measurements were acquired on a Magnetom 7T whole body scanner (Siemens Healthcare Sector, Germany) with an 8 channel volume coil (RAPID Biomedical GmbH, Germany).

Results: The histograms of the B0 maps for the three subjects are given in Figure 2, and show that the vast majority of spins lie within ±200Hz. The simulation of B0 profiles, Figure 1, showed that to achieve an inversion efficiency greater than 95% the HS1 requires a γB_1>300Hz, and the HS8 γB_1~280Hz. In comparison, the FOCI pulse at a γB_1 of 200Hz causes the central frequencies to experience 95% inversion efficiency, the effect of increasing γB_1 is to increase the frequency range which experiences a 95% inversion efficiency. Additionally the FOCI's pass band is free from ringing, and the maximum inversion efficiency seen at high γB_1 is 97.8%, 98.2% and 97.4% for the HS1, HS8 and FOCI pulses respectively.

The uniform MP2RAGE images shown in Figure 2 provide examples of where the HS1 fails to invert the spins, either due to large B0 offsets (white arrow) or low γB_1 (black arrows). At the large B0 offset frequencies located near the sinus cavities both the HS8 and FOCI pulses invert the spins; however the HS8 pulse results in a better depiction of the underlying orbital gyrus structure. At low γB_1, and small Δb0 offsets, the HS8 shows some improvement over the HS1 pulse but in regions of very low γB_1 (<230Hz), i.e. in the cerebellum or close to the ear canals, only the FOCI pulses shows significant improvement in inversion efficiency. Table 2 shows that the T1 values obtained with the HS8 and FOCI in 4 regions within the brain have a good agreement with the HS1 pulse across the different subjects. The small differences are in part due to the small differences in peak inversion efficiency compared to the assumed inversion efficiency used to calculate the T1maps.

Discussion: The HS8 pulse showed that in regions with a large B0 offset it is able to improve the inversion efficiency; however like the HS1 it struggles to invert the spins in areas of very low γB_1 such as the cerebellum. The HS1 and HS8 pulse behave similarly, as γB_1 increases the inversion efficiency increases until the spins are fully inverted. In contrast the FOCI pulses ability to fully invert the central frequencies at very low γB_1 (~200Hz) enables regions, such as the cerebellum and close to the ear canals, to experience a better inversion. In areas with a large B0 offset, close to the sinus, sufficient γB_1 is required to ensure complete inversion with the FOCI pulse. **In conclusion** the use of the optimized FOCI pulse best improves the inversion in regions of low γB_1 appearing when whole-brain coverage in acquisitions such as MP2RAGE or double inversion recovery acquisitions is desired.

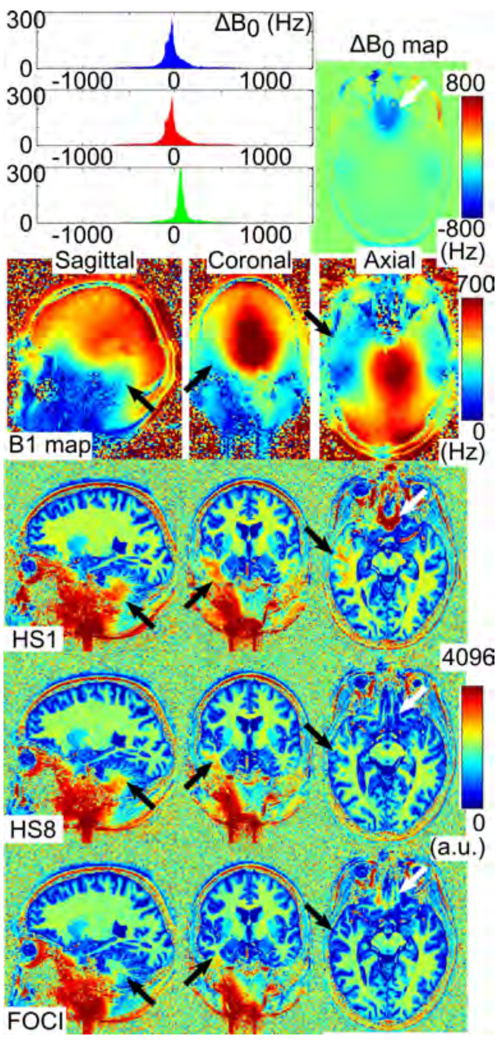

Figure 2 shows the uniform MP2RAGE image acquired with each adiabatic inversion pulse and the corresponding B1 and ΔB0 maps at various orientations. The histogram represents the ΔB0 offsets over the entire brain for the three subjects.

References: **[1]** Garwood M. 153(2001)155 JMR **[2]** Marques J. 49(2010)1271 Neuroimage **[3]** Hurley A.C.63:(2010):51 MRM **[4]** Jezzard P. 34(1995)65 MRM **[5]** Eggenschwiler F (2011) MRM

Subj	Corpus Callosum Genu			Corpus Callosum Splenium			Caudate			Amygdala		
	HS1	HS8	FOCI	HS1	HS8	FOCI	HS1	HS8	FOCI	HS1	HS8	FOCI
1	1113±155	1127±74	1149±61	1045±63	1072±61	1120±93	1624±81	1598±121	1586±71	1839±179	1852±172	1833±121
2	1100±65	1112±63	1137±70	1106±81	1145±87	1123±87	1637±68	1663±78	1676±83	1732±133	1785±135	1738±136
3	1081±75	1087±66	1095±75	1077±42	1187±52	1120±37	1717±61	1704±99	1721±103	1886±155	1843±139	1923±147
1(rep)	1085±82	1152±69	1143±76	1065±58	1139±67	1088±45	1615±66	1690±68	1622±57	1965±91	1896±104	1892±79

Table 1 Average (±σ) T1 values for region of interests across three subjects, including one repeat scan.