High contrast imaging at high field strengths with low SAR

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Introduction: High magnetic field strengths offer the well known advantages of better signal-to-noise and better spectral resolution. They do, however, have some drawbacks. One of the them is an increase in radiofrequency (rf) power deposition. This is an important limitation in terms of general patient safety and more so for patients with neuro-implants [1, 2]. And yet the ability to image patients with implants, with low power deposition is very important. In this abstract, we present a means by which rf power deposition can be reduced by a factor of 25 to 200 and yet obtain images similar in contrast to both T1 and T2 weighted images, by employing simple low flip angle (FA) spin density weighted imaging. We show that this contrast in magnitude approaches that of conventional T1 contrast at high fields.

Theory: The contrast at high fields can be simulated using the measured and estimated longer T1s for gray matter and white matter [3-5]. Here we consider only the short TR, short TE steady state incoherent gradient echo sequence. In the limit of TR<<T1 and very log flip angles, a simple expression for the contrast between two tissues with different spin densities and T1s, is found to be:

$$Contrast = (\rho_1 - \rho_2) * \theta - \frac{\theta^3 * (\rho_1 * T_{1a} - \rho_2 * T_{1b})}{2 * TR}$$

Using the values given in Table 1 for spin density (rho) and T1, contrast is plotted between WM/GM (as WM-GM), GM/CSF (as GM-CSF), and Blood/GM (as Blood-GM) at 4T in Figure 1a. The peak contrast value (for WM/GM) for the usual T1 weighted approach at 22° flip angle is now comparable in magnitude to the ultra-low flip angle contrast peak (approx. 60% of the high FA contrast peak). In fact, considering the increase in signal with the field strength (w.r.t 1.5T, by a factor sqrt(B_0/1.5)), this negative contrast peak increases as the T1 increases with the field strength, showing a minima and maxima in the contrast curve (Figure 1b).

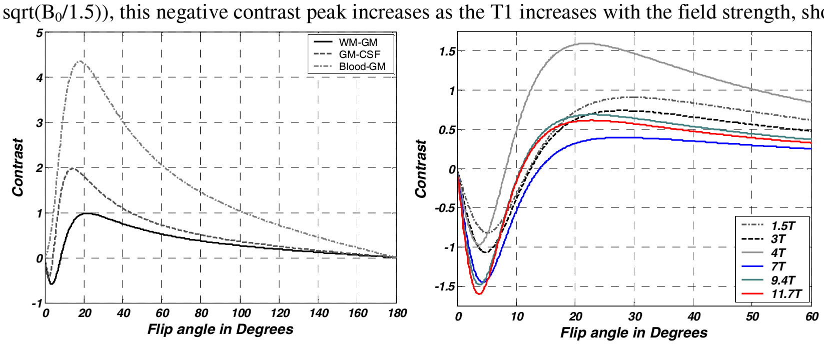

Figure 1 a) Contrast plot between, GM/WM, GM/CSF and GM/BLOOD at 4T. A reduction in blood T1 due to inflow affect (10 cm/sec in a 128 mm slab) was assumed for contrast calculation. b) GM/WM contrast at different field strengths (weighted relative to 1.5T, by a factor sqrt (B_0/1.5)), plotted as a function of flip angle.

Materials and Methods: 3 human volunteers were imaged on a 4.0 T Bruker/Siemens Med-spec machine. Informed consent was obtained from all the volunteers. The protocol included: a) A 3D SSI scan with flip angles 2° and 20°, b) a standard T1 MPRAGE and c) turbo spin echo proton density-T2 sequence. The sequence parameters were as follows: 3DGRE (TR/TE) 20/5 ms with a BW = 100 Hz/Pixel and resolution of 1 x 1 x 2 mm^3, 64 slices; T1 MPRAGE, (TR/TI/TE) 1500/700/5.53 ms, FA 8°, and BW = 130 Hz/pixel; Turbo spin echo PD/T2, (TR/TE1(PD)/TE2(T2)) 4000/18/105 ms, turbo factor 5, and a TH = 4 mm. GdDTPA (Magnevist; Berlex NJ, USA) was used for two volunteers. After contrast administration they were imaged with a 4° flip angle sequence. In addition to the above sequences, one volunteer was imaged with 1°. The 1° degree data was acquired twice and averaged to improve the signal-to-noise ratio (SNR).

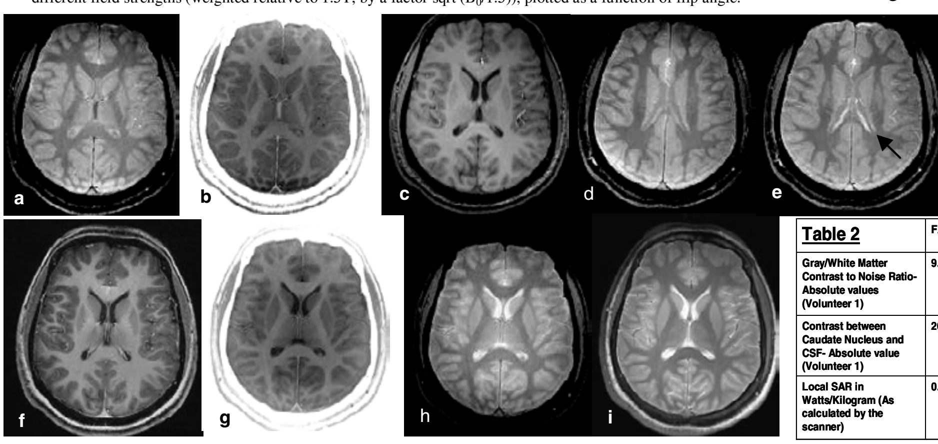

TABLE 1 T1 values across Different Magnetic Field Strengths	1.5T (ms)	3T (ms)	4T (ms)	7T (ms)	9.4T (ms)	11.7T (ms)	Relative Spin Densities
Gray Matter	1000	1300	1724	1906	2264	2493	80
White Matter	650	900	1043	1425	1630	1823	65
CSF	4000	-	-	-	-	-	100
Arterial Blood	2000	-	-	-	-	-	85

Table 2	FA 1°	FA 2°	FA 4°	FA 20°	MPRAGE T1 (Flip angle 8°)
Gray/White Matter Contrast to Noise Ratio-Absolute values (Volunteer 1)	9.945772	12.69951	17.75162	17.4213	17.6515
Contrast between Caudate Nucleus and CSF- Absolute value (Volunteer 1)	20.5925	21.57875	5.918407	36.58876	29.0224
Local SAR in Watts/Kilogram (As calculated by the scanner)	0.00266	0.00643	0.04256	1.06406	1.904

Figure 2: Comparing visually, CNR between low FA FLASH and conventional imaging sequences. **a**) 4^0 flip angle (FA) image (FLASH). **b**) Inverted 4^0 image. **c**) Conventional 20^0 T1 weighted FLASH image. **d**) MIP (maximum intensity projection) of 4^0 images over 8mm. **e**) MIP of Post Contrast 4^0 image. **f**) Conventional T1 weighted MPRAGE with FA 8^0. **g**) Inverted 2^0 FA image. **h**) 2^0 image. **i**) Spin density (Spin Echo) image.

Results: The actual CNR (magnitude) in each case, along with the associated rf power deposition is shown in Table 2. As predicted by the theory, the absolute value of contrast between gray and white matter at 4° and 20° is quite similar (see Fig. 2b, and c), with 25 times less RF power deposition. The contrast between caudate nucleus and CSF at 4° is much lower than that obtained at 20°. Therefore, we also compare the CNR at 2° (see Fig 2 g (inverted), h) with the CNR at 20° and find that the CNR is now improved for the caudate nucleus and CSF. The contrast at 2^0 (Fig 2h) is heavily spin density weighted, as is seen when we compare that to the contrast in a conventional spin density (spin echo) image (Fig 2i). The effect of a T1 reducing contrast agent at 4^0 is shown in Figure 2 d and e. Clearly there is enough T1 weighting to enhance the vascular signal.

Discussion and Conclusion: This concept is easily extended to higher fields such as 7T, 9.4T and 11.7T. The T1 values at four field strengths were obtained from the literature (at 1.5, 3, 4 and 7 T) [3, 4, 5] and then used to fit the parametric equation $T_1 = A * f^B$, where f is the field dependent resonant frequency and A, B are the parameters [6]. The results in Figure 2 and Table 2 demonstrate that the low flip angle images from a short TR, rf spoiled steady state incoherent sequence can provide good CNR images which are mainly spin density weighted and yet, when inverted provide pseudo-T1 contrast images. A point to note is that due to the inflow effect, the blood in the large vessels appears bright at 4 degrees and therefore appears dark on inversion. The fact that we see the effect of the contrast agent (CA) at 4° implies that low FA imaging can successfully be applied for lesion detection in cases where Blood Brain Barrier breaks down and CA accumulation occurs. In conclusion, the viability of using a low flip angle, steady state incoherent, gradient echo sequence for structural imaging with low rf power deposition at high fields has been successfully demonstrated.

References:1) Henderson et al., Neurosurgery. 2005 Nov;57(5):E1063. 2)Rezai Et Al., Invest Radiol., 2004;39: 300–303. 3) Norris DG., JMRI, 2003;18:519–529. 4) Duewell S. et al, Radiol. 1996; 199:780-786. 5) Bottomley PA et al, Med. Phys. 1984; 11: 425.