Disentangling different Gadolinium concentrations: a comparison between High Field and Very Low Field MRI.

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Purpose Gadolinium based Contrast Agents (CA) are often used in Magnetic Resonance Imaging (MRI) to improve the diagnostic accuracy of many brain pathologies[1-3]. When CAs are in an aqueous solution, the molecular motion causes fluctuations in the dipolar coupling between the magnetic moment of the paramagnetic ion Gd^{3+} and the magnetic moments of the protons of the surrounding water molecules thus reducing their relaxation times[4]. Previous studies have investigated the dependence of the relaxation rates (r1) on the magnetic field strength of MultiHance, Gadovist and of other Gd-chelates[5] varying also the Gd^{3+} concentration ([Gd])[6,7]. Because at Ultra an Very Low Field (ULF-VLF) the r1-values increase while the total signal-loss due to magnetic susceptibilities decreases, the enhanced contrast is especially achieved in T1-weighted images[8]. For this reason we aim here at presenting a characterization of different concentrations, in solution, of MultiHance and Gadovist using an MRI scanner operating at 8.9 mT. In recent years many laboratories have developed ULF and VLF MRI scanners[9,10], starting to use them also for in-vivo measurements[11,12]. However, the diffused used of gadolinium based contrast agent in the diagnosis of brain diseases was never studied at these low field strengths. Here we present a pilot work showing how the contrast of images of different Gd-concentrations changes varying the applied field (8.9 mT, 0.2 T, 1. 5 T and 3 T).

Methods Different dissolutions (1:3000, 1:2000, 1:1000, 1:500) of MultiHance and Gadovist in copper sulphate, $CuSO_4$+H_2O, and a sample of this solvent were studied. All the samples were contained in tubes of 1.5 ml. T1-weighted images were acquired using a Spin-Echo sequence varying the Repetition Time (TR) with four devices operating at: 8.9 mT, 0.2 T (Artoscan, Esaote, Genova), 1.5 T and 3T (Philips Achieva, Philips Medical System, Best, the Netherlands). The Echo Time (TE) was choosen as the smallest permitteted by each scanner (19 ms for 8.9 mT, 18 ms for 0.2 T, 8 ms for 1.5 T and 12 ms for 3T). The intra-voxel signals were fitted on the function $S(T_R)=A(1-exp(-T_R/T_1))+E$ where $A=S_0exp(T_E/T_2)$ and E is the noise. In a second step each signal was rescaled in order to have a dependence only on the longitudinal relaxation process $S'(T_R)=1-exp(-T_R/T_1)$. Because r1 and [Gd] are linked by the relation[5] $1/T_{1,obs}=(r_1)_{obs}=(r_1)_s+(r_1)_p[Gd]$, the contrast between two different concentrations $([Gd]_M$ and $[Gd]_m$ with M>m) $C=S'([Gd]_M)-S'([Gd]_m)=exp(-T_R(r_{1,obs})_m)(1-exp(-T_R r_{1,p}\Delta[Gd])$ is maximized by $T_R*\sim 1/r_{1s}=T_1([Gd]=0)$ if we want maximize contrast in an image showing also [Gd]m=0. We considered $\Delta[Gd]=([Gd]_M-[Gd]_m)>0$.

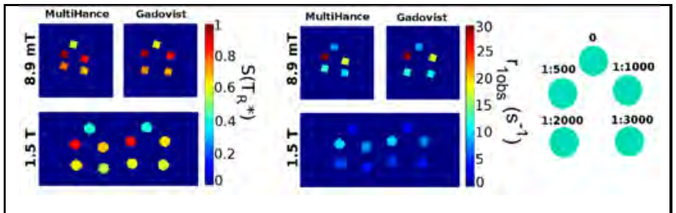

Figure 1: (Left) T1 weighted images of the MultiHance and Gadovist phantoms of tubes of different [Gd]s. (Right) the corresponding r1 maps with the scheme of the dissolutions in each phantoms.

Results Figure 1 shows images obtained at 8.9 mT and at 1.5 T, where falsecolors were applied to the grayscale. On the left we show T1-weighted rescaled images containing only the information about T1 (taken for TR=T1s, specific for each field); on the left we show the r1- maps in which each pixel is the r1 value obtained by fitting the intra-voxel signals as a function of TR. Figure 2 reports the linear dependence of the r1 values from the Gd concentration (upper) together with the dependency of the r1 values with the field strength for each sample (bottom). In figure 3 contrast in r1 maps and in T1-weighted images are shown as a function of Δ[Gd], for different [Gd]m. Contrast in the r1 maps has been calculated as $(r_{1,obs})_M-(r_{1,obs})_m=(r_1)_p\Delta[Gd]$.

Discussion Analysing the original and rescaled signals it is possible to obtain a range of TR values maximizing signal-intensities and contrast between different [Gd] concentrations. Images in Figure 1 suggest that the [Gd] concentrations are more differentiated in r1 maps that in the T1-weighted images, where contrast appears similar at VLF and 1.5 T. Notably, at VLF this differentiation in the r1 maps is better. In fact, Figure 2 shows that the concentrations of MultiHance and Gadovist have very different relaxation rates at this field strength. This implies that the best way to distinguish different [Gd], is analyzing the r1 maps at VLF (see also the contrast trend in the r1 maps in the upper part of Fig.3). Contrast in signals at all the fields are similar for the different $[Gd]_m$ concentrations.

Conclusions The present work represents the first study concerning the imaging of gadolinium-based Contrast Agents at very low magnetic field strength, the new frontier of MRI. By using a scanner operating at 8.9 mT and three scanners used in the clinical practice at higher fields (0.2 T, 1.5 T and 3 T), we have demonstrated that there is not an improvement in the use of high magnetic field strengths to distinguish between Gadolinium concentrations. Additionally, we introduced the r1-mapping at 8.9 mT as a method enhancing the identification of different Gd-concentrations. Since at LF a lower concentration of contrast agent is needed to observe the same relaxation rate of higher fields, by using this method risks to patients due to the toxicity of gadolinium will be reduced.

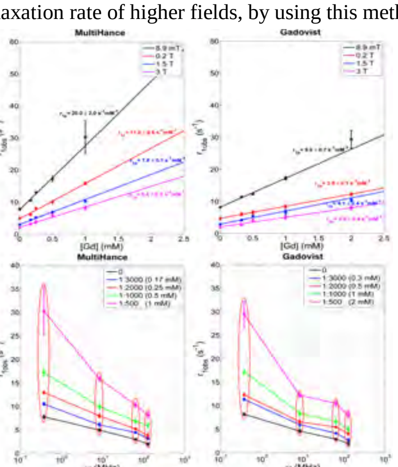

Figure 2: (Upper) the linear relationship between r1 values and [Gd], for the different dissolutions of MultiHance and Gadovist. (Bottom) Changes of $r_{1,obs}$ as a function of the magnetic field strength.

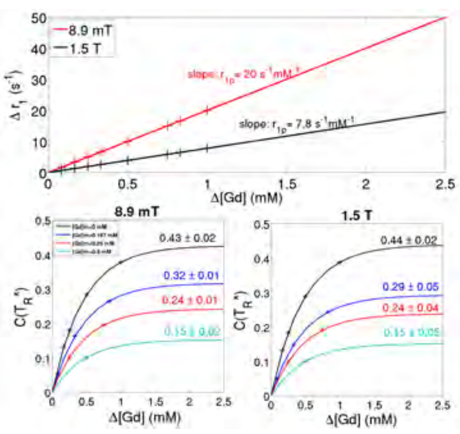

Figure 3: (Upper) contrast between different [Gd] in the r1 maps at 8.9 mT is better than that at 1.5 T. Here Δ[Gd]=[Gd]m-[Gd]M. (Bottom) contrasts between signals . Each curve refers to a different [Gd]m. These trends show that there is not an improvement in the use of high fields strengths.

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