Contrast Agent Optimization for Imaging with MR/x-ray Hybrid Systems

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Introduction

We have studied the properties of MR and x-ray contrast agents in order to develop an imaging contrast medium that is suited for simultaneous visualization in both MR and x-ray images. Such a contrast medium could be used in our MR/x-ray hybrid system [1] that combines an x-ray fluoroscopy unit within the bore of a 0.5T GE Signa SP (GE Milwaukee, WI) interventional magnet and could eliminate the need for re-catheterization in some procedures such as cystography. It would also remove any deleterious effects of residual iodine from previous iodine injection on MR image signal enhanced by gadolinium contrast (Gd-contrast), as has been documented in the literature [2]. Also it would allow better registration of x-ray and MR images obtained by the hybrid imager by co-registration of vessel trees that are simultaneously observed in the MR and the x-ray images of the same anatomy.

Methods and Material

The T1 and T2 relaxivities (R1 and R2) of iodine and of Gd-contrast agent solutions in saline, and saline solutions containing both dyes simultaneously, were evaluated. The measurements were performed in a 1.5T GE Signa SP (GE Milwaukee, WI) magnet using a standard head coil. The pulse sequence used for measuring T1 values was a standard Inversion Recovery (IR) sequence with TR/TE = 3000/9 ms with TI ranging from 50 to 400 ms. For measuring T2 values, a standard Spin Echo (SE) sequence was used with TR = 2500 ms and TE ranging from 10 to 1000 ms. The Gd-contrast agent used was 0.5M Gd-DTPA (Magnevist, Berlex Lab., Wayne, MI) and the saline used was a 0.9% Sodium Chloride solution (Aqualite System, Abbott Labs., Chicago, IL). The iodine contrast agent that was primarily studied was of the kind that is commonly used in cystography, diatrizoate meglumine (Hypaque-cysto, Amersham Health Inc., Princeton, NJ) (HPC) and contains 300 mgI/ml. Some other x-ray contrast media that are commonly used clinically were also studied in their native state to evaluate their potential for use in the contrast agent mixture for MR/x-ray imaging. These include Conray (Mallinckrodt Inc., St. louis, MO (202 mgI/ml)), Reno-30 (Bracco Diagnostics, Princeton NJ (300 mgI/ml)), and Omnipaque (Winthrop Pharm., New York, NY (647.1 mgI/ml)). Table 1 lists the solutions that were imaged for evaluation of their T1 and T2 relaxation properties.

Results and Conclusions

For Gd-contrast agent in saline as well as HPC solutions in saline, the inverse of the T1 and the T2 values follow the usual linear relation as established in the literature[3] (see Table 1). While the R1/R2 ratio for Gd-contrast is about 0.94, this ratio is 0.24 for HPQ. This suggests that HPQ shortens T2 more severely than T1. The mixture of different concentrations of Gd-contrast in a 1:1 HPC:saline solution also had a very linear trend for 1/T1 and 1/T2 with an approximate increase of 38-39% for the values of R1 and R2 for Gd-contrast. The R1/R2 ratio remained fairly unchanged. Finally, the combination of varying concentrations of HPC in a solution with 0.1% Gd also followed a linear trend for 1/T1 and 1/T2. Fig. 1 shows a T2 weighted SE image (TR/TE=2500/120 ms) of 6 vials of 10 ml of the above solution with 300 mgI/ml HPQ concentration ranging from 50% to 100% by volume. The signal degradation with increasing amounts of HPQ are clearly visible in the coronal slice shown in Fig 1 with 50% HPQ solution in top left vial, 100% HPQ in bottom right vial with other concentrations increasing from left to right and top to bottom in increments of 10%. The ratio R1/R2 for these solutions was found to be 0.68 which is an increase of almost 180% from the R1/R2 ratio for HPQ in absence of Gd-contrast.

Solution composition	***Percent by volume of contrast (%)***	***R1 ($mMol^{-1}\ s^{-1}$ kg of water***	***R2 ($mMol^{-1}\ s^{-1}$ kg of water***	***R^2 of 1/T1 fit***	***R^2 of 1/T2 fit***
Gd-contrast* + Saline	0.1, 0.2, 0.3, 0.4, 0.5	5.32	5.63	0.9949	0.9989
HPC*+ Saline	50, 60 70, 80, 90, 100	0.0018	0.0075	0.9966	0.9969
Gd-contrast* + (HPC + saline [1:1])	0.1, 0.2, 0.3, 0.4, 0.5	7.34	7.84	0.9987	0.9987
HPC* + Gd-contrast (0.1%) + saline	50, 60 70, 80, 90, 100	0.0129	0.0191	0.9527	0.9754
Omnipaque	100	T1(ms)=477.34	T2(ms)=89.29		
Conray	100	T1(ms)=720.57	T2(ms)=212.77		
Reno	100	T1(ms)=1054.76	T2(ms)=102.04		
** component of the solution whose concentration was varied*					

Table 1 Contrast agent solutions that were studied for T1 and T2 relaxivity properties.

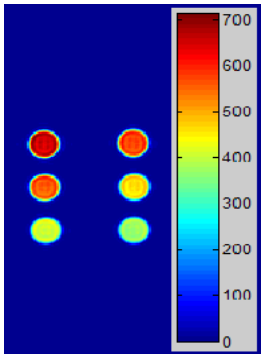

Fig. 1 T2 weighted SE images of vials with 0.1% Gd and varying concentrations of HPQ

These results suggest that the relaxivity of Gd-contrast and HPQ are each modified by the presence of the other. It has been proved through spectro-photometric studies [4] that Gd-contrast and iodine do not interact chemically. Since R1 and R2 were found to be constants for a fixed amount of Gd-contrast with varying HPQ as well as for constant HPQ and varying Gd-contrast, therefore the usual relaxivity equation should have the following modified form: $1/T_{1Gd} = 1/T_{1I} + R_{1Gd}(X_I)X_{Gd}$ .....(1) where X denotes the molar concentration of the contrast agent. A similar equation should hold true for HPQ as well as for the 1/T2 relationships. This dependence of the relaxivity of one contrast agent on the presence of the second has been suggested in the literature [3] where the changing macromolecular environment of Gd was found to change its relaxivity properties. This dependence has been suggested to be linear though it was found to be quadratic for certain macromolecules in a solution of Gd-contrast. Since the R2/R1 ratio for Gd-contrast appears to remain unchanged with changing iodine concentration, one possible method for improving the T2 to T1 ratio or equivalently image SNR would involve lowering the iodine concentration. However dilution of iodine would affect its x-ray attenuation which falls off exponentially with density. Therefore, the tradeoff in x-ray signal per MR signal improvement would have to be evaluated for the specific study. Another possibility is to utilize a different iodine contrast agent that has a better T2 to T1 ratio. The T1 and T2 values measured for some of the other iodine media shown in Table 1, suggest Conray as having a high T2 to T1 value.

In conclusion, the relaxivity properties of iodine and Gd-contrast agents have been studied revealing the severe T2 shortening effects compared to T1 shortening of iodine contrast. Based on preliminary results, possible combinations of Gd-contrast and iodine have been suggested and SNR tradeoffs have been discussed. Detailed evaluation of the relaxivity of the combined contrast agent is required before calculation of the optimal combination can be carried out.

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References [1] Fahrig *et al* JMRI 13:294-300 [2] Montgomery *et al* JMRI 15:334-343 [3] Stannisz *et al* MRM 44:665-667 (2000). [4] Brown *et al* AJR 175:1087-1090 (2000)