# Quantification of the Relaxation Times of Combined CT and MR Contrast Agents for Optimal Imaging at MR Arthrography

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## Introduction

Using both iodinated X-ray contrast and gadolinium (Gd) based MR contrast agents is helpful when performing MR arthrography. Joint visualization is enhanced if fluoroscopy is used for needle placement and a CT exam can be performed without an additional needle stick if the MR arthrogram is unsuccessful. However, the presence of iodinated contrast alters the relaxivity of gadolinium based MR contrast agents [1]. In order to optimize the image contrast for MR arthrography, the effect of iodinated contrast agents on the relaxation property of Gd contrast must be understood [2].

The purpose of this study is to measure the T1 and T2 relaxation times of solutions with different combinations of Gd and iodine concentrations and at different magnetic field strengths in order to model their dependences. Such information can then be used to predict the optimal gadolinium and iodine concentrations for direct arthrography for a given MRI protocol.

## Methods

Three different type of Gd contrast agents, MultiHance (gadobenate dimeglumine, Bracco, Princeton, NJ), ProHance (gadoteridol, Bracco, Princeton, NJ) and Magnevist (Gd-DTPA, Berlex, Wayne, MI) were mixed with a single iodinated contrast agent, Isovue-370 (iopamidol 76%; Bracco, Princeton, NJ) and diluted with clinical-grade saline (0.9% sodium chloride solution) to produce three sets of solutions with different Gd concentrations of 2, 1, 0.5, 0.25, 0.125, 0 mmol/L and iodine concentrations of 370, 185, 92.5, 46.25, 0 mg/mL. Vials filled with these Gd and iodine mixtures were embedded in Play-Doh prior to MRI scans.

Measurement of relaxation times was made using GE 0.7T OpenSpeed, Siemens 1.5T Symphony and Siemens 3.0T TIM Trio scanners. An IR-FSE sequence with ETL of 3, TI times of 50, 100, 200, 400, 800, 1600, 4000 ms and TR of 10 sec were used to acquire images for T1 mapping. A SE sequence with minimum TE times possible for each scanner (10-16 ms) as well as 20, 40, 80, 160 and 320 ms and a TR time of 3.5 sec was used to acquire images for T2 mapping. A non-linear least squares fitting algorithm was used to calculate the T1 and T2 values pixel by pixel [3], and a user defined ROI was placed inside each sample region in the T1 and T2 maps to estimate the T1 and T2 relaxation times for each combination of Gd and iodine concentration. Finally, for each field strength and type of Gd contrast agent, the T1 and T2 relaxation times were fitted with two-variable linear models: $1/T1 = R_{01} + R1_{Gd}[X_{Gd}] + R1_I[X_I] + R1_{Gd\_I}[X_{Gd}][X_I]$ and $1/T2 = R_{02} + R2_{Gd}[X_{Gd}] + R2_I[X_I] + R2_{Gd\_I}[X_{Gd}][X_I]$, where $[X_{Gd}]$ and $[X_I]$ are Gd and iodine concentrations, to determine the coefficients: $R1_0$, $R1_{Gd}$, $R1_I$, $R1_{Gd\_I}$, $R2_0$, $R2_{Gd}$, $R2_I$ and $R2_{Gd\_I}$.

## Results

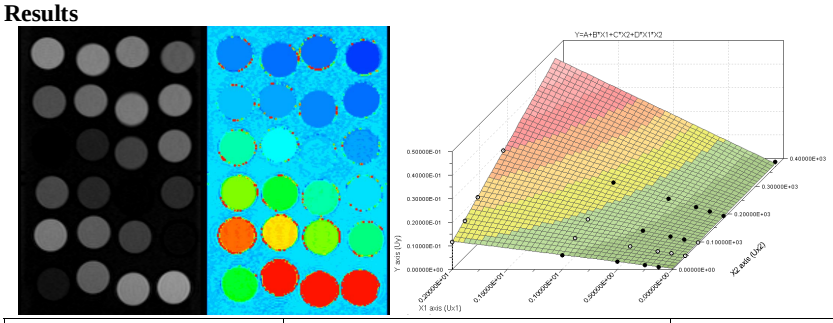

Figure 1 a) Representative image of MultiHance and Isovue mixtures acquired with TI=200ms at 1.5T. b) T1 map of MultiHance and Isovue mixtures at 1.5T. c) Two-variable regression of T1 values of MultiHance and Isovue mixtures with different concentrations.

| MR Contrast | MultiHance | | | ProHance | | | Magnevist | | |
|---|---|---|---|---|---|---|---|---|---|
| Field Strength | 3.0T | 1.5T | 0.7T | 3.0T | 1.5T | 0.7T | 3.0T | 1.5T | 0.7T |
| $R1_0$ ($x10^{-1}s^{-1}$) | *3.48±0.26* | *2.62±0.43* | *2.84±0.65* | *2.45±0.42* | *2.81±0.40* | *2.73±0.76* | *2.56±0.42* | *2.42±0.59* | *2.37±0.66* |
| $R1_{Gd}$ ($mM^{-1}s^{-1}$) | *5.77±0.11* | *6.10±0.25* | *6.87±0.33* | *4.36±0.15* | *4.42±0.17* | *5.09±0.26* | *4.63±0.13* | *4.91±0.22* | *5.59±0.25* |
| $R1_I$ ($x10^{-3}mM^{-1}s^{-1}$) | *0.93±0.13* | *1.50±0.18* | *1.85±0.25* | *1.64±0.14* | *1.36±0.19* | *1.88±0.31* | *1.36±0.16* | *1.51±0.20* | *2.02±0.29* |
| $R1_{Gd\_I}$ ($x10^{-2}mM^{-2}s^{-1}$) | *1.70±0.06* | *1.90±0.15* | *2.14±0.19* | *1.12±0.09* | *1.26±0.12* | *1.47±0.16* | *1.27±0.08* | *1.29±0.13* | *1.48±0.15* |
| $R2_0$ ($x10^{-1}s^{-1}$) | *6.12±0.83* | *6.17±0.78* | *9.00±0.88* | *5.54±0.58* | *5.06±0.46* | *9.28±0.51* | *6.91±1.25* | *6.17±0.92* | *8.69±1.13* |
| $R2_{Gd}$ ($mM^{-1}s^{-1}$) | *7.12±0.17* | *7.02±0.21* | *6.48±0.20* | *5.30±0.10* | *5.38±0.11* | *5.27±0.12* | *5.57±0.22* | *5.65±0.23* | *5.64±0.22* |
| $R2_I$ ($x10^{-2}mM^{-1}s^{-1}$) | *3.58±0.11* | *2.24±0.08* | *1.11±0.04* | *3.68±0.06* | *2.41±0.04* | *1.26±0.03* | *3.13±0.13* | *2.19±0.08* | *1.21±0.06* |
| $R2_{Gd\_I}$ ($x10^{-2}mM^{-2}s^{-1}$) | *1.72±0.29* | *2.27±0.21* | *1.99±0.15* | *1.89±0.12* | *1.50±0.13* | *1.51±0.10* | *2.13±0.26* | *1.60±0.27* | *1.28±0.14* |

Table 1. Coefficients for relaxation rate of MultiHance, ProHance and Magnevist mixed with Isovue 370 and saline at 0.7T, 1.5T and 3.0T

## Discussion

Our data substantiates the relaxation coefficients for Magnevist seen in previously published results [2], and demonstrates that the coefficients are very similar for ProHance. MultiHance produced a significantly higher degree of T1 and T2 relaxation (although not by a magnitude of 2, as described in prior *in vivo* experiments). The T1 relaxation rates of both iodine ($R1_I$) and Gd ($R1_{Gd}$) are seen to increase with a decrease of magnetic field strength. The proposed generalized relaxation relations will theoretically allow the concentrations of a variety of commonly used Gd agents and iodinated contrast agent to be optimized for MR arthrography in order to achieve the desired contrast for a variety of MR protocols at different field strengths. As an example, for routine MR arthrography using a 50-50 dilution of Isovue 370 and normal saline, the signal intensity for typical T1 protocols (e.g., SE TR/TE=600/10) is maximized with the following amounts of gadolinium agents by volume: ProHance 0.11% @ 0.7T, 1.5T and 3.0T; Magnevist 0.10% @ 0.7T and 0.11% @ 1.5T and 3.0T; MultiHance 0.07% @ 0.7T, 0.08% @ 1.5T, and 0.09% @ 3.0T. In clinical practice, marginally higher gadolinium concentrations may be required due to physiologic dilution by pre-existing synovial fluid; this will require further *in vivo* investigation to clarify. The greatest T1 relaxation effect occurs with MultiHance.

## References

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