

## R1 and R2\* changes according to Gd concentration: a potential limiting factor in converting MR signal intensity to Gd concentration

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**Background:** When converting MR signal intensity (SI) to Gd concentration, it is generally assumed that R2\* effect is negligible and R1 change is linear to Gd concentration. However, Gd at high concentration, particularly when measuring arterial input function on DCE-MR, this assumption might be inaccurate because non-linear change of R1 and significant increase of R2\* may occur. For example, when assuming that 0.1 mmol/kg of Gd is fully diluted in the plasma of healthy male subject (plasma volume, 3 L), the plasma concentration of Gd must be 2.5 mM or greater, while in practice. However, in practice, Gd concentration measured at arteries on MR by using conventional converting methods, is often less than 2.5 mM.

**Purpose:** To evaluate the effect of changes in R1 and R2\* at clinically relevant Gd concentrations when converting SI to Gd concentration on MR.

**Materials and Methods:** *In vivo* - In a normal male SD rat, blood sampling was performed at left femoral artery after bolus injection of Gd-DTPA (0.1 mmol/kg) (each sampling volume: 50  $\mu$ l; sampling time: 19 - 900 sec). The concentration of Gd was measured using inductively coupled plasma (ICP) mass spectrometry. *Phantom* - MR images were obtained on a 1.5 T unit (Avanto: Siemens, Erlangen, Germany). Phantoms with clinically relevant Gd concentrations (2.5, 5.0, 7.5, 10.0, 12.5, 15.0, 17.5, 20.0, 22.5, 25.0, 30.0 mM) were used for measuring R1 and R2\* values. R1 values were measured using ultrashort TE sequence with various flip angles (TR, 76 msec; TE, 0.05 msec; flip angle range, 5° - 90°; flip angle incremental interval, 5°). T2\* values were estimated using multi-echo FLASH sequence (TR, 20 msec; TE: 1.65 - 15.65 msec, incremental interval, 2 msec).

**Table 1.** T1 and T2\* according to Gd concentration

Gd concentration (mM)	R1 (1/sec)	R2* (1/sec)
2.5	0.63	39
5.0	1.623	31
7.5	2.44	23
10.0	2.73	17
12.5	2.80	13
15.0	2.81	11
17.5	2.82	11
20.0	2.82	9
22.5	2.83	7
25.0	2.82	6
30.0	2.82	5

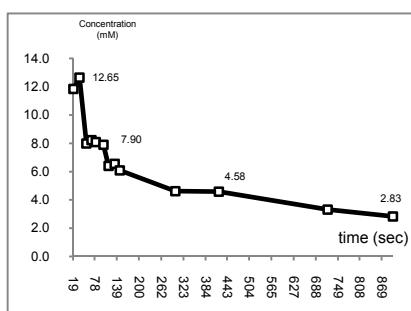


Fig. 1. Gd concentrations at femoral artery after bolus injection (0.1 mmol/kg of Gd-DTPA)

**Results:** According to the results of ICP mass spectroscopy, the plasma concentration of Gd increased to 12.64 mM in 36 sec and reduced to 2.83 mM in 900 sec after bolus injection (Fig 1). The measured R1 and R2\* values according to Gd concentration in phantoms are summarized in Table 1. The changes of R1 did not show linear correlation with Gd concentration, as the R1 reached to plateau approximately from 7.5 mM (Fig. 2). R2\* value according to Gd concentration increased with an exponentially increasing pattern (Fig. 2). In the simulation of SI/M<sub>0</sub> values, SI/M<sub>0</sub> decreased at high Gd concentrations, such as from mM or greater (Fig. 3 and 4) although it increased at concentration window of 2.5 to 7.5 mM.

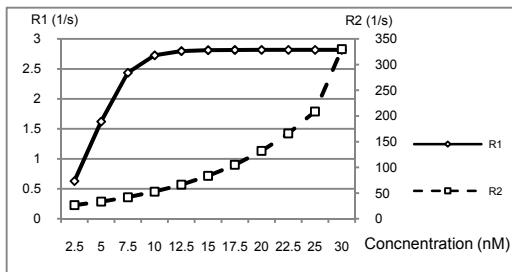


Fig. 2. R1 and R2\* values according to Gd concentration

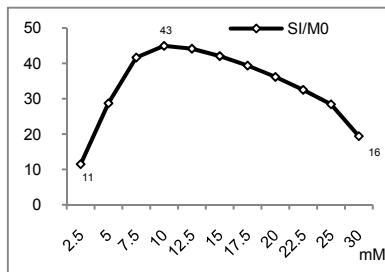


Fig. 3. Simulated signal-intensity/proton-density at various Gd concentrations

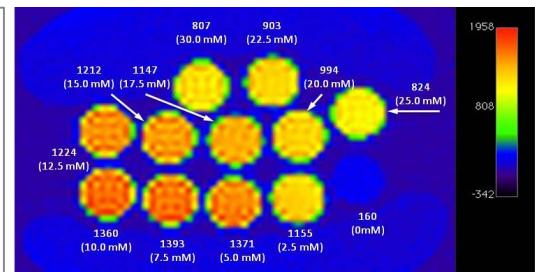


Fig. 4. Color map of MR images (TR, 20 msec; TE, 4.02 msec; flip angle, 30°) of phantoms at various Gd concentrations. Signal intensity and Gd concentration are demonstrated for each phantom.

**Conclusion:** Administration of 0.1 mmol/kg of Gd leads to plasma concentration ranging from 2.83 to 12.64 mM in arteries. Non-linear relationship between the changes of R1 and Gd concentration and exponential increase of R2\* according to Gd concentration may cause incorrect conversion of SI to Gd concentration on MR, particularly at high Gd concentration windows. To reduce these effects, lower concentration of Gd should be administrated, particularly in measuring of arterial input function on dynamic contrast-enhanced MR.