Effects of water exchange on MR quantification of regional myocardial blood flow using an intravascular T1 contrast agent

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Introduction

Dynamic contrast-enhanced MRI using T1-weighted imaging and an intravascular contrast agent might be a promising tool to quantify regional myocardial blood flow (rMBF) *in vivo* (1). This approach relies on basic tracer kinetic models based on measurements of an indicator concentration. However, MR signal enhancement measures the effects of the contrast agent on tissue water magnetization rather than contrast agent concentration. The accuracy of perfusion measurements therefore depends on whether modeling hypothesis are fulfilled by the experiment. One of the main concerns is related to the impact of water movement on the longitudinal relaxation rate R1 and hence on MR signal. Larsson et al (2) have shown that water exchange can have a significant effect on brain perfusion estimation using the T1-weighted technique. The same study could not be performed in the heart because there was no intravascular contrast agent available for this organ. The aim of our study was to quantitatively investigate the effects of water exchange between the vascular and extravascular compartment on rMBF quantification when using a prototypic intravascular contrast agent in pigs.

Materials and Methods

Perfusion-weighted MRI was performed in 5 healthy pigs at rest and under adenosine-induced stress using a T1-weighted Turbo-FLASH imaging sequence (repetition time 2.4 ms; inversion time 176 ms; number of phases: 112; flip angle: 8°; field of view: 30-cm; matrix 256x256 voxels; slice number: 2; 60 images per slice obtained at intervals of approximately 1 s triggered by ECG) during intravenous bolus injection of a macromolecular contrast medium (P717, r1=9.4 $mmol^{-1}.s^{-1}$ at 60 MHz, Guerbet, Aulnay-sous-bois, France) at the dose of 0.009 mmol/kg. Carotid blood samples were withdrawn every second to provide first-pass blood concentration-time curves. Pre-contrast R1 were calculated on the basis of a set of ten similar images obtained with inversion times that varied between 20 and 5000 ms. The modified Bloch equations taking into account the mean residence times τ_{blood} and $\tau_{myocardium}$ of water protons in the respective compartments were solved in order to establish the relationship between MR signal intensity and ΔR1 defined as the difference between post- and pre-contrast R1. Relative vascular compartment size was assumed to be 10% at rest and 15% under stress conditions. MR signal-time curves were then converted into ΔR1-time curves in 12 myocardial sectors for each pig (Figure 1). The central equation for determining rMBF using an intravascular indicator is given by: $C_{tissue}(t) = rMBF \cdot C_{artery}(t) \otimes R(t)$ where R(t) is the residue function of the system. Deconvolution of this equation was performed using an ARMA model and the assumption of a linear relationship between ΔR1 and concentration of contrast agent in blood (1). Radioactive microspheres were used as a gold standard for regional blood flow measurements.

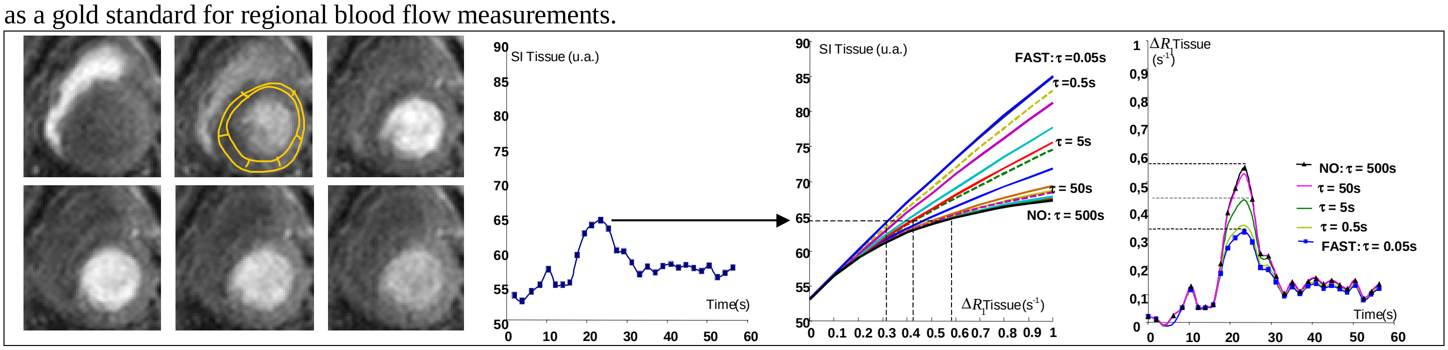

Figure 1- Conversion of MR signal into ΔR1 according to water exchange regimen (SI: signal intensity)

Results

Table 1 shows the values obtained for 3 different exchange rates ($1/\tau = 1/\tau_{blood} + 1/\tau_{myocardium}$). This study confirms the dependency of rMBF measurements on water exchange regimen hypothesis. Myocardial perfusion was best approximated using fast exchange regimen though ΔR1 analysis overestimated rMBF for both rest and stress conditions when compared to microspheres results.

	microspheres	Fast (τ=0.05 s)	Intermediate (5 s)	Slow (500 s)
rest	96 ± 12	177 ± 80	242 ± 103	305 ± 139
stress	644 ± 80	649 ± 155	937 ± 178	1122 ± 180

Table 1- regional myocardial blood flow in ml/min/100g (mean ± standard deviation in 12 sectors)

Conclusion

There is not yet a standard protocol for myocardial perfusion imaging using T1-weighted MRI and an intravascular contrast agent. Using an intravascular contrast agent eases the kinetic modeling but makes the technique more sensitive to water exchanges. Since water diffusion impact cannot always be neglected, caution should be taken when designing perfusion MR sequences in order to minimize these effects and thus increase the accuracy of perfusion estimates.

References

(1) Neyran et al, Magn Reson Med 2002;48(1):166; (2) Larsson et al, Magn Reson Med 2001;46(2):272.