Quantification of Myocardial Blood Volume and Water Exchange with Intravascular Contrast Agent

O. Biris[1,2], N. Chatterjee[3], D. C. Lee[3,4], and J. Carr[1,3]

[1]Radiology, Northwestern University, Chicago, IL, United States, [2]Biomedical Engineering, Northwestern University, Evanston, IL, United States, [3]Feinberg School of Medicine, Northwestern University, Chicago, IL, United States, [4]Cardiology, Northwestern University, Chicago, IL, United States

Introduction

Quantification of absolute myocardial blood volume (ml/min/100g tissue) has the potential to timely diagnose and reduce patient mortality from coronary artery disease. A method has been previously developed to quantify organ perfusion by direct calibration of *relative* perfusion images using absolute blood volume (1). It is well known that for an intravascular gadolinium-based T_1 shortening contrast agent, the parenchymal T_1 change reflects tissue blood volume. However, to accurately quantify blood flow from blood volume, we must describe the effects of intra- to extra-vascular water exchange (2). We propose a method for absolute quantification of myocardial blood volume (MBV) by using an intravascular contrast agent. A number of intravascular contrast agents, including albumin bound and USPIO, have come to the market; we chose to use MS-325 based on availability.

Materials and Methods

Protocol In an instrumented dog we measured T_1 using a cardiac gated Modified Look Locker Inversion Recovery (MOLLI)(3) pulse sequence (slice thickness 8 mm, FOV 171 x 343 mm^2, matrix 96 x192, TR 173 ms, effective TI 100 ms). Images were acquired on a 1.5 T Espree scanner (Siemens Medical Systems, Erlangen, Germany), during a short breath-hold, 5 minutes after injections of 0.003 mmol/kg of MS-325(Ablavar, Lantheus Medical Imaging, Billerica, MA).

Image Processing We estimated the myocardium and left ventricle blood pool T1 through fitting of MOLLI signal to the regrowth curves of the Look-Locker equation by an automatic image processing program developed in MATLAB R2009a (Mathworks, Natick, MA, USA). MBV was calculated from the baseline to post-contrast change in T_1 in the blood pool and myocardium, according to Equation 1.

$$MBV_{FastExchange} = \frac{R_{1\,pre-constrast}^{tissue} - R_{1\,post-contrast}^{tissue}}{R_{1\,pre-constrast}^{blood} - R_{1\,post-contrast}^{blood}}$$

(1), where $1/T_1 = R_1$

$$MBV_{noExchange} = \frac{S_{pre-constrast}^{tissue} - S_{post-constrast}^{tissue}}{S_{pre-constrast}^{blood} - S_{post-constrast}^{blood}}$$

(2)

MS-325 has a marked T_1 shortening effect, even in small concentrations

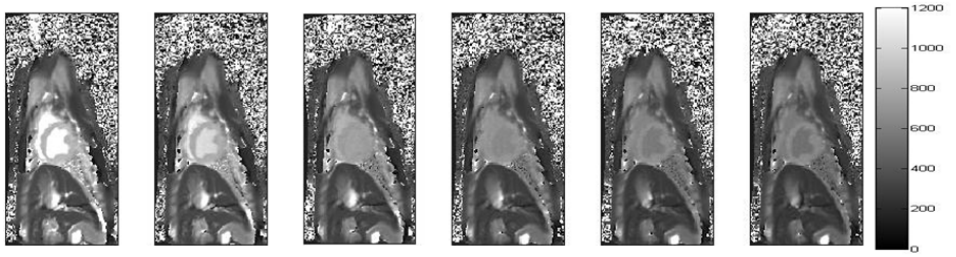

Fig. 1 Preliminary results mapping T_1 (ms) in a canine heart under incremental cumulative changes in concentration of MS-325. Baseline and T_1-enhanced images are used to quantify myocardial blood volume.

	Baseline	0.003 mmol/kg	0.009 mmol/kg	0.015 mmol/kg	0.021 mmol/kg	0.027 mmol/kg
T_1(LV) ms	1259±63	1018±33	761±15	645±19	580±16	548±33
T_1(myocardium) ms	871±88	818±76	727±52	676±49	634±69	624±42

Results

Low dose injections of MS-325 effected significant changes in myocardial T_1's (Figure1).The measured MBV was 40% of total myocardial volume, or 28 ml/100g, a value that over-estimates those quoted in the literature (4). Water exchange in the myocardium was shown to approach the slow or no-exchange limit (Equation 2, Figure 2).

Conclusions

We have established an imaging protocol to measure MBV and water exchange, in animal or human subjects. Over-estimation of MBV may be caused by extravasation of MS-325, and to a lesser extent by T_2 bias on the T_1 measurements with the steady-state free precession MOLLI sequence. Future steps include measuring MBV with a strictly intravascular USPIO contrast agent, application of a more sophisticated fit that includes T_2 effects, and determination of the water exchange constant by Monte-Carlo simulations.

MBV Calculations Show Slow Water Proton Exchange

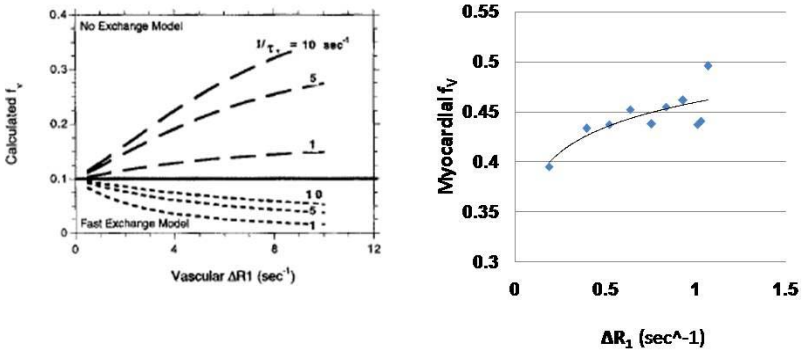

Figure 2 Vascular fractions fv predictions based on "No exchange" and fast exchange limits for a range of exchange values (left). Preliminary results from our experiments suggest the "No exchange" limit is appropriate for the quantification of myocardial blood volume (right).

References

1. Sakaie KE et al. J Magn Reson Imaging 2005;21(5):512-519.
2. Donahue KM et al. Magn Reson Med 1996;36(6):858-867.
3. Messroghli DR et al. Magn Reson Med 2004;52(1):141-146
4. Bjornerud A, et al. Magn Reson Med 2003;49(5):828-837.