SUPPLEMENTAL MATERIAL

Supplemental Methods

MR Oxygenation Imaging

We have established our theoretical modeling and experimental method to calculate regional myocardial OEF in vivo (1). In brief, myocardial magnetization in a voxel was described with a 2-compartment model: intravascular and extravascular. In T_2-weighted images acquired by a turbo spin-echo (TSE) sequence with an interecho spacing τ (the time difference between two consecutive 180^o pulses), the signal in a myocardial tissue voxel can be approximated in a biexponential form as follows:

$$\frac{S_{voxel}(TE)}{S_0} = e^{-\frac{TE}{T_{2app}}} = MBV \times e^{-\frac{TE}{T_{2b}}} + (1 - MBV) \times e^{-\frac{TE}{T_{2t}}} \quad [1]$$

where S_{voxel} is the mean signal intensity of the voxel at TE; S_0 is a variable related to the proton density of the voxel, receiver gain, and T_1 of the tissue; T_{2app} is apparent myocardial T_2; and MBV is the intravascular blood volume fraction. T_{2b} and T_{2t} are the T_2 values of blood and tissue, respectively. Because the TEs of 60 ms in our T_2 measurement were much less than the intracapillary residence time of water spins (>250 ms), a slow exchange was assumed in this model. Using the Van Zijl's intravascular component model (2), intravascular T_2 can be derived:

$$\frac{1}{T_{2b}} = A'OEF^2 + B'OEF + C' \quad [2]$$

where A', B', and C' are the functions of magnetic susceptibilities, interecho spacing τ, oxygenation-dependent T_2 of erythrocytes and plasma, TE, arterial oxygen saturation (Y_a), and hematocrit. These constants can be derived with experimental data obtained at 1.5 T (3). The extravascular T_{2b} can be approximated using a diffusion model (4, 5):

$$\frac{1}{T_{2t}} = R_{20t} + R_{21t} OEF^2 MBV^2 \tau^2 \qquad [3]$$

where R_{20t} is the intrinsic myocardial tissue transverse relaxation rate, and R_{21t} is a function of the diffusion constant (D), susceptibility difference between blood vessel and surrounding tissue, geometry of the heart relative to the B_0 static field, and the size of capillary and venous vessels. Both parameters are subject-specific and need to be determined individually. With the application of at least two different τ, corresponding T_{2t} at rest can be calculated using Eq. [1]. If we assume the resting value of OEF at 0.6, using the measured resting MBV data from the first pass perfusion imaging, the subject-specific parameters R_{20t} and R_{21t}, can be estimated at rest with Eq. [3] by acquiring MRI T_2 data in two different τ values. With knowledge of R_{20t}, R_{21t}, myocardial OEF during the hyperemia can be calculated through Eqs. [1–3] with apparent myocardial T_2 and measured MBV.

Imaging of myocardial oxygenation was performed with a BOLD sequence that measures myocardial T_2 signals as described previously (1). The imaging sequence for this technique was a multi-contrast 2D segmented turbo spin-echo (TSE) sequence that collected T_2-weighted images. To minimize flow artifacts in the left ventricle, double-inversion-recovery preparation yielded black-blood images. The sequence was ECG-triggered with the segmented TSE train placed in the motionless period of mid-diastole to minimize cardiac motion. Imaging parameters included: FOV = 220 x 131 mm^2; matrix size = 256 x 156; slice thickness = 8 mm; inversion time = 350-500 ms, segmentation number = 3, depending on the RR interval; and data acquisition time = 24 x RR, or 14.4 s for a typical 600 ms RR interval. Three echo times were used TE_1 = 24, TE_2 = 48, TE_3 = 72. This sequence was executed twice at rest with two different echo spacings (τ = 8 and τ = 12 ms) to calculate R_{20t}, R_{21t}. During the hyperemia, BOLD sequence was run multiple times at τ = 8 ms only.

Supplemental References

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