Intravoxel Incoherent Motion and Arterial Spin Labeling MRI of Isolated Perfused Hearts

Osama Abdullah[1], Arnold David Gomez[1], Samer Merchant[1], Michael Heidinger[2], Steven Poelzing[2], and Edward W Hsu[1]

[1]*Bioengineering, University of Utah, Salt Lake City, Utah, United States,* [2]*Cardiac Research and Training Institute, University of Utah, Utah, United States*

Introduction Myocardial blood flow (MBF) changes are often associated with, and occur before detectable structural or functional alterations in cardiac diseases. Intravoxel incoherent motion (IVIM) is a diffusion-like phenomenon that is sensitive to tissue microcirculation (1), which depends on the vascular volume fraction (VF) and the mean speed of capillary blood flow quantified as the pseudo diffusion coefficient (D*). Despite of recent studies that measured IVIM in beating hearts (2,3), the relationship between IVIM and the underlying myocardial capillary organization, which has implications for in vivo microstructural measurements based on diffusion MRI or diffusion tensor imaging (4), remain incompletely understood. In this study IVIM was investigated in an animal model of isolated, arrested perfused hearts as functions of precisely controlled MBF and diffusion encoding direction. The IVIM parameters were directly correlated to independent measure of MBF using arterial spin labeling (ASL) (5).

Methods Isolated guinea pig hearts (n=7) were perfused in a Langendorff apparatus and imaged with Bruker Biospec (7T) MRI scanner under normal (aortic pressure 52 mmHg) and low (16 mmHg) flow conditions as described previously in detail (6). ASL and diffusion scans were performed on the same short-axis slice using flow-sensitive-inversion-recovery and diffusion weighted spin echo EPI sequences, respectively (6). Diffusion was encoded in both slice and readout directions using b-values: 1, 7, 18, 28, 55, 80, 107, 157, 200, 310, 513, 766, and 1020 s/mm^2. Subsequently, the observed diffusion signal was averaged over regions of interest in the mid-wall circumferential fiber that is parallel to the read (in short axis) and perpendicular to the slice axis. The standard IVIM signal equation (7), $S = S_0\left[(1-f)e^{-bD} + fe^{-b(D+D^*)}\right]$, was fitted, where D is the tissue apparent diffusion coefficient (assuming the intrinsic $D_{blood} = D$), and f is the VF. A segmented approach was used to estimate the IVIM parameters D, D^* and f as described recently (8). Separately, MBF was estimated from the ASL image intensities using previously described procedures (9). IVIM parameters were compared using 2-way ANOVA (encoding direction and flow setting) using Bonferroni correction for post-hoc multiple comparisons, and correlated to ASL using linear regression analysis.

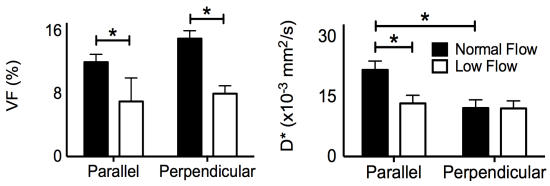

Figure 1. IVIM-derived vascular VF (left) and mean blood flow velocity (right) measured for different inflow pressures and myofiber orientations. Asterisks (*) denote a Bonferroni-corrected P<0.05.

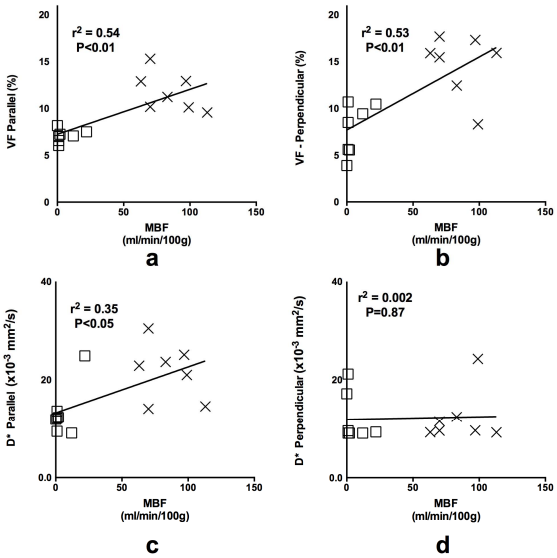

Figure 2. Scatter plots of ASL-derived MBF and the VF (a) and D* (c) parallel to myofibers, and the VF (b) and D* (d) perpendicular to myofibers. The r^2 and associated P-values are included with each graph.

Results Figure 1 shows the IVIM parameters (VF and D*) as a function of flow setting and encoding direction. D* encoded in the parallel direction was larger than the perpendicular direction at normal flow. VF decreased by 66% and 90% from normal to low inflow pressure in both parallel and perpendicular directions, respectively. In contrast, D* significantly decreased only in the parallel direction (by 63%). Figure 2 shows the scatter plot and correlation of individual IVIM parameters and ASL-derived MBF. VF in both directions show strong correlation with MBF, whereas only the parallel D* correlated significantly with MBF.

Discussion and Conclusions The behaviors of D* with respect to myofiber orientation and MBF indicate that blood flow is faster in the direction parallel than perpendicular to myofibers, which is consistent with previous reports that capillaries in the heart follow the myofiber orientation (10). The VF was found to depend only on MBF but not myofiber orientation. Although the lack of fiber orientation dependence is in contrast to a previous study (2), intuitively, VF is a scalar measurement of compartmental size, and as such it should not depend on encoding direction. In conclusion, the results indicate that IVIM parameters measured in the perfused myocardium vary as function of degree of microcirculation and myofiber orientation in fashions that are consistent with the known anatomy and circulation physiology of the myocardium.

References 1. Le Bihan et al.; *Radiology*. 1988;168(2):497–505. 2. Callot et al.; *Magn Reson Med*. 2003;50(3):531–40. 3. Delattre et al.; *Invest Radiol*. 2012;47(11):662–70. 4. Scott et al.; *Magn Reson Med*. 2014. 5. Reeder et al.; *Radiology*. 1999;212(3):739–47. 6. Abdullah et al., Proceedings of the 21st Annual Meeting of ISMRM. *Salt Lake City;* 2012. 7. Le Bihan et al.; *Radiology*. 1988;168(2):497–505. 8. Federau et al.; *AJNR* 2014;35(2):256–62. 9. Iltis et al.; *JMRI*. 2005;22(2):242–247. 10. Poole et al.; *Am J Physiol Hear Circ Physiol*. 1990;259:204–10. **Acknowledgments** This work was supported by NIH R01 HL092055.