# *In vivo* Characterization of Myocardial Microstructure in Normal and Infarcted Hearts Using the Supertoroidal Model

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**Introduction:** The supertoroid-based representation of cardiac diffusion tensor MRI (DT-MRI) has previously been shown to enhance the three-dimensional perception of myocardial tissue structure and organization.[1] Moreover, the toroidal model provides an index of diffusivity, the toroidal volume (TV) and a coefficient of anisotropy, the toroidal curvature (TC).[2,3] Hence, the purpose of this work is two-fold: (1) to assess the reproducibility of TV and TC measurements *in vivo* and compare them with measurements of mean diffusivity (MD) and fractional anisotropy (FA), and (2) to quantify the changes in TV, TC, MD and FA in infarcted myocardium.

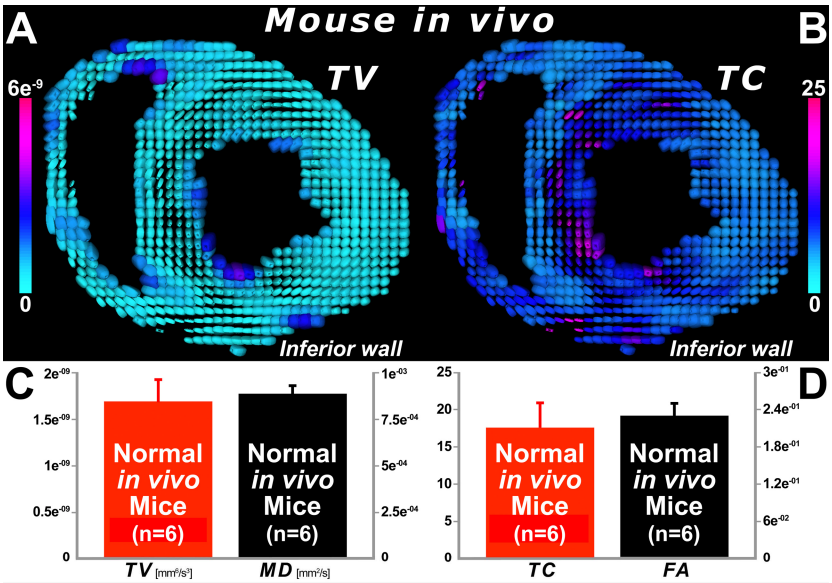


**Figure 1:** (**A**) *In vivo* supertoroidal field of a mid-ventricular short axis slice in a mouse heart, colored according to the TV index. (**B**) Supertoroidal field colored according to TC. (**C**) Bar plot depicting the mean and SEM of TV and MD in 6 mice. Both indices yield highly reproducible values with small measurement error (SEM). (**D**) Bar plot (mean and SEM) of TC and FA, indicating that the levels of anisotropy are highly reproducible *in vivo*.

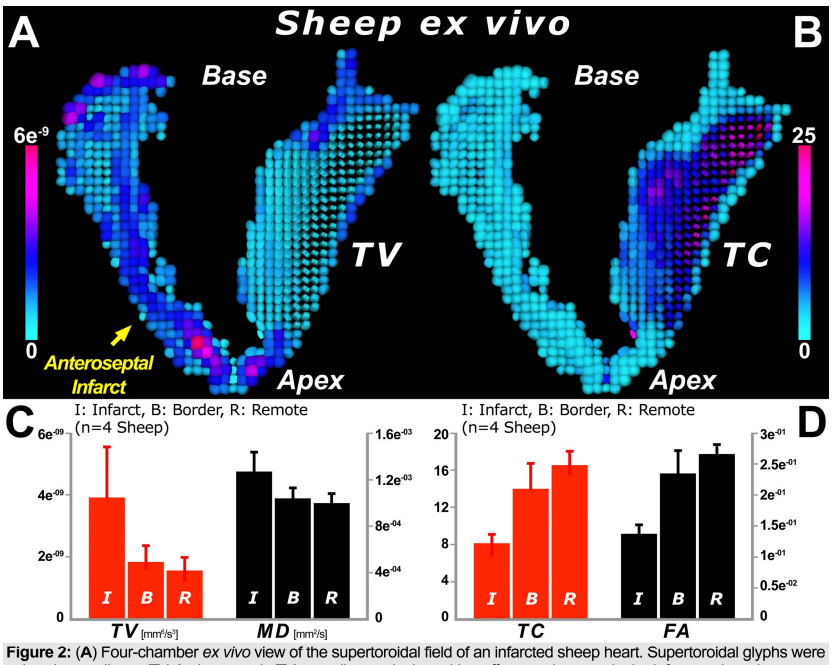


**Figure 2:** (**A**) Four-chamber *ex vivo* view of the supertoroidal field of an infarcted sheep heart. Supertoroidal glyphs were colored according to TV. An increase in TV as well as a glyph packing effect can be seen in the infarct region when compared to the lateral wall. (**B**) Supertoroidal field colored according to TC, indicating higher anisotropy values in the remote areas compared to the infarct. (**C**) Bar plot describing mean and SEM of TV and MD in 4 sheep hearts in which regions of interest were defined in the infarct (I), border (B) and remote (R) zones. Greater differences are seen in TV than MD between infarcted and non-infarcted myocardium. (**D**) Bar plot depicting mean and SEM for indices TC and FA, indicating a consistent decrease in anisotropy between the I and B, and I and R regions.

**Methods:** DT-MRI of infarcted sheep hearts (n=4) was performed *ex vivo* on a 3T scanner using 32 gradient-encoding directions; a b-value of 2000s/mm$^2$; voxel-size=2x2x2mm$^3$; TR/TE=8430/96ms. *In vivo* DT-MRI of the mouse hearts (n=6) was performed on a 9.4T scanner with a 1500 mT/m gradient and a 3D fat-suppressed single-shot 3D spin echo EPI sequence. Motion-compensated bipolar diffusion-encoding gradients were applied on either side of the 180° RF pulse. Other parameters of the in-vivo sequence included: TR/TE=2000/13.5 ms, b-value 500 - 700 sec/mm$^2$ with 24 gradient-encoding directions, and isotropic resolution of 280 µm. Mean and standard error of the mean (SEM) were computed for TV, TC, MD, and FA within a region of interest (ROI) in the lateral wall of the mouse hearts. TV, TC, MD, and FA were calculated in the sheep hearts in the infarcted (I), border (B) and remote (R) zones.

**Results:** **Fig. 1A** shows the supertoroidal field of an *in vivo* short axis image of a mouse heart, colored according to the TV index. **Fig. 1B** displays the same supertoroidal field color-coded with TC. Both diffusivity (TV) and anisotropy (TC) are relatively homogeneous in the normal mouse hearts. The reproducibility of the TV and TC indices *in vivo* was high (**Fig. 1C** and **1D**). In normal myocardium TV and TC provided analogous information to MD and FA.

Four-chamber views of a supertoroidal field in an infarcted sheep heart are shown in **Fig. 2A** (TV) and **Fig. 2B** (TC). A distribution of higher TV values is found within the infarct region, depicting structural disorganization due to breakdown of the extracellular matrix. A greater difference between infarcted and non-infarcted tissue was seen with TV when compared to MD (**Fig. 2C**). A significant decrease in TC as well as in FA (**Fig. 2D**) within the infarct is consistent with the observed increase in TV and is the result of myofiber loss.

**Conclusion:** The quantification of DT-MRI data using the supertoroidal model is performed *in vivo* for the first time. TV and TC values in the myocardium *in vivo* are relatively homogeneous and highly reproducible. Changes in diffusivity in infarcted myocardium are detected with greater sensitivity with TV than MD. The use of the supertoroid formalism thus holds significant promise for the analysis of myocardial microstructure with DT-MRI.

**References**: 1. Mekkaoui C *et al*. ISMRM 2010. 2. Mekkaoui C *et al*. JCMR 2010. 3. Mekkaoui C *et al*. ISMRM 2010. **Funding:** R01 HL093038 (Sosnovik), NCRR P41RR14075 (Martinos Center), and MGH-ECOR (Mekkaoui).