ASSESSMENT OF MYOCARDIAL HETEROGENEITY USING THE SUPERTOROID-BASED REPRESENTATION OF DT-MRI

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INTRODUCTION

The supertoroid-based representation of cardiac DT-MRI was previously shown to enhance cardiac myofiber structure characterization compared to ellipsoids, superquadrics and toroids **[1]**. The supertoroidal model is an evolution of the toroid-based representation and provides a new index of diffusivity the toroidal volume (TV) **[2,3]** and a new coefficient of anisotropy the toroidal curvature (TC). TV has been shown to characterize the cardiac remodeling process post-MI **[4]**. The purpose of this study is to establish the normal myofiber structure of the left ventricle (LV) using our new toroid-based indices (TV and TC) and traditional diffusion indices mean diffusivity (MD) and fractional anisotropy (FA) in normal porcine hearts.

METHODOLOGY

Diffusion anisotropy is classically quantified by the FA, which represents the eccentricity of the ellipsoidal tensor representation. Using the supertoroidal model, one can derive a new anisotropy coefficient based upon the curvature of the toroidal surface. This new coefficient, the toroidal curvature (TC), quantifies the maximal Gaussian curvature of the toroidal surface and is defined as:

$$TC = \frac{4\beta'\gamma'^2\cos\phi_M}{(\alpha'+\beta'\cos\phi_M)\left[\beta'^2+\gamma'^2+(\gamma'^2-\beta'^2)\cos 2\phi_M\right]^2} \quad \begin{cases} \alpha' = (2\lambda_2+\lambda_3)/4\lambda_1, \beta' = \lambda_3/4\lambda_1, \gamma' = 1/2. \\ \phi_M = \arg\max_{\phi}\{tc(\phi)\}, \phi \in [0,\pi] \end{cases}$$

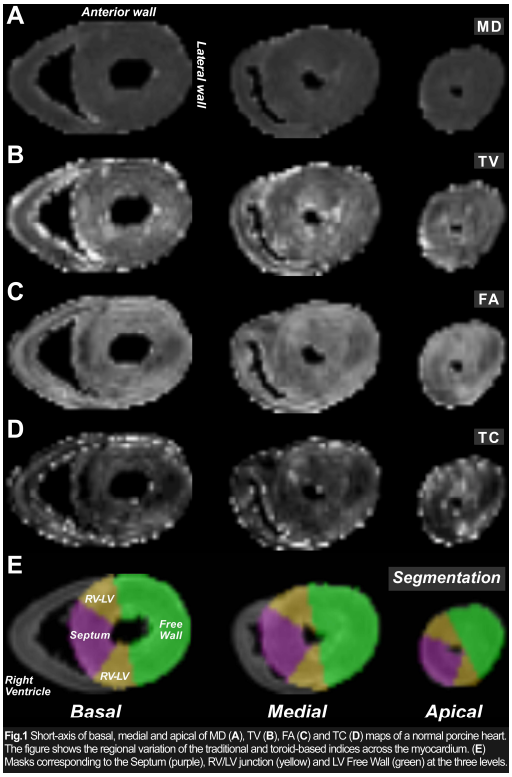

Fig.1 Short-axis of basal, medial and apical of MD (**A**), TV (**B**), FA (**C**) and TC (**D**) maps of a normal porcine heart. The figure shows the regional variation of the traditional and toroid-based indices across the myocardium. (**E**) Masks corresponding to the Septum (purple), RV/LV junction (yellow) and LV Free Wall (green) at the three levels.

The variation of diffusivity and anisotropy within LV was evaluated in 7 normal porcine hearts using TV and TC and traditional indices MD and FA. For analysis purposes, each LV was divided into apical, medial (mid-ventricular), and basal levels and each level was subsequently segmented into Septum, RV/LV junction, and Free Wall (FW). Mean values of each index were computed for all segments within and across levels. Variation in the diffusion indices across regions were assessed non-parametrically using the Friedman test and post-hoc sign tests were conducted to identify regions with statistically different values ($p<0.05$). ***Data Acquisition*:** Animals were euthanized and hearts were excised and perfused with saline. Each heart was then placed in a container and filled with Fomblin (Ausimont, Thorofare, NJ). DT-MRI was performed on a 3.0T Siemens Trio scanner (Erlangen, Germany) using a segmented EPI sequence, 6 gradient directions; b-values=0s/mm^2 (T2-weighted) and 600s/mm^2; voxel-size=2×2×2mm^3; 50 short-axis slices; TR=5400ms; TE=84ms; 40 averages (EPI factor=7).

RESULTS

Fig.1 illustrates the diffusion maps MD (**A**) and TV (**B**), as well as the anisotropy maps FA (**C**) and TC (**D**) for one heart at the basal, medial, and apical levels. **Fig.1E** depicts the Septum, RV/LV junction and FW segments used in the analysis. A degree of structural heterogeneity can be observed on the diffusion maps depicted by **Fig.1**. Quantification of diffusivity and anisotropy maps indicated a significant variation in structure across and within levels (**Fig.2**). While TV displayed significant apex to base differences in both FW and Septum, MD detected significant differences only in the Septum. It was found that both TV and MD successfully differentiated Septum from RV/LV junction at basal and medial levels. However, TV defined differences between RV/LV junction and FW also at the apical level. While TC displayed differences only in the FW, FA showed significant differences in both Septum and FW regions. TC and FA show similar differences at medial and apical levels, however only TC was able to detect differences at the basal level between regions.

DISCUSSION

Quantification of DT-MRI in normal hearts showed that LV macrostructure was heterogeneous in terms of both diffusivity and anisotropy. TV and TC exhibited heterogeneity in the LV within and across levels, revealing a regional structural pattern. Furthermore, TV may be more sensitive for evaluating changes in diffusivity than MD, because of the volumetric nature of this index. The measure of curvature (TC) also demonstrates to be capable of detecting structural differences within the LV. The results obtained with TV and TC corroborates the observed regional variations in diffusivity and anisotropy as measured by the ellipsoid-based indices showed by Jiang *et al*. **[5]** and provides an increased understanding of the regional differences of the LV fiber structure.

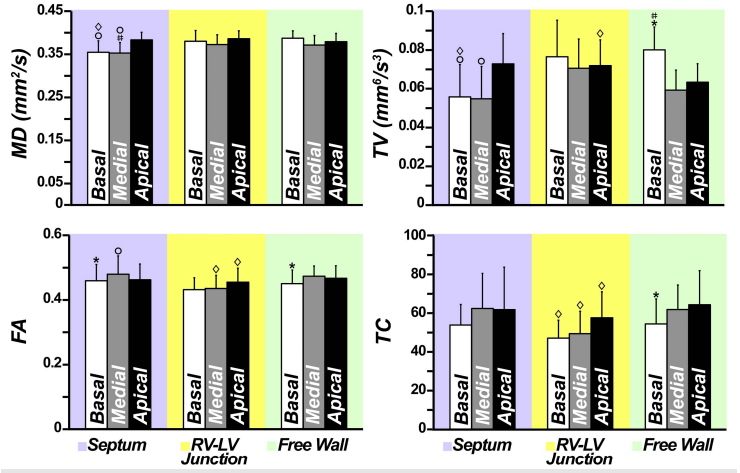

Fig.2 Bar plots representing mean and standard deviation values of MD, TV, FA and TC at basal, medial and apical levels for Septum (purple), RV/LV junction (yellow) and LV Free Wall (green). The following symbols denote a significant difference within a region (across levels) or between regions (within the same levels): * $p<0.05$ *vs.* medial within levels; # $p<0.05$ *vs.* apical within levels; ○ $p<0.05$ *vs.* RV/LV junction; □ $p<0.05$ *vs.* LV Free Wall. These results show that diffusivity and anisotropy are heterogeneous within the LV.

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References: **[1]** Mekkaoui C *et al*. ISMRM 2009; **[2]** Mekkaoui C *et al*. BMES 2007; **[3]** Mekkaoui C *et al*. ISMRM 2008; **[4]** Mekkaoui C *et al*. JCMR 2009; **[5]** Jiang *et al*. Am J Physiol 2007.