Identification of Myocardial Infarction using Fractional Anisotropy of 3D Strain Tensors

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INTRODUCTION: Accurate localization of regional myocardial viability is important in clinical diagnosing of infarction. Assessment of myocardial viability is typically accomplished by delayed-enhanced (DE) magnetic resonance imaging (MRI) with injection of gadolinium [1]. Meanwhile, the normal range of myocardial strain patterns as function of position in myocardium and time during the cardiac cycle has been previously studied [2] providing a reference with which strains in infarcted regions can be compared. Although three-dimensional (3D) strain tensor provides extensive amount of information, adoption of these information into clinical practice is rare. This is mainly due to the fact that 3D strain fields are mathematically more complex and computationally more intractable than the data in scalar images. Therefore, it is desirable to represent multivariate myocardial strain tensors with simplified scalar indices that are correlated with viability. Tensors can be described as ellipsoids consisting of three orthogonal vectors that each has a direction and an associated magnitude. It is hypothesized that infarcted tissue will neither compress nor elongate as much as in healthy, active muscle, and therefore has a less directional strain tensor. Anisotropy, the property of being directionally dependent, can transfer the information of 3D strain tensor into a scalar measure that is easier to interpret. In this work, MR tissue tagging is used to calculate 3D strain tensors. Fractional anisotropy (FA) is calculated and used to identify regions of myocardial infarction. In-vivo results show strong correlation with delayed enhancement without negative effects associated with contrast agents.

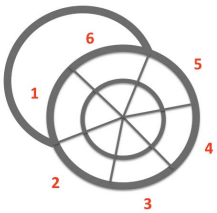

Figure 1.a Segmental Model

METHODS: Myocardial infarction (MI) was induced by LAD coronary artery ligation in five pigs. Multi-slice zHARP [3] tagged and DE viability images were acquired 10-20 days after infarction on a 3.0T Achieva whole body MRI scanner (Philips Medical Systems, Best, NL), equipped with a six-channel cardiac phased array surface coil. Channels were distributed equally between the anterior and posterior sides of the chest. 8-10 short axis slices from the base to apex were acquired using VECG triggered spiral imaging with a 9 ms acquisition window, 10 spiral readouts, 256 samples, FOV = 320 mm, resolution = 1.25x1.25mm, slice thickness = 8 mm, TR = 20 ms, tag period = 7 mm, and $\kappa = 2\pi/33$ rad/mm. All the data were acquired using segmented k-space spiral acquisition.

zHARP applies an additional z-gradient of different polarities in the slice-select direction of the tagged image, which provides ability of tracking 3D motion of the imaged slice. By forming rectilinear mesh of points on a stack of equally separated images, Eulerian finite strain is calculated for each spatial point during all cardiac cycles. FA, a number between 0 and 1 representing the degree of anisotropy, is calculated using $FA = \sqrt{3((\lambda_1-\bar{\lambda})^2+(\lambda_2-\bar{\lambda})^2+(\lambda_3-\bar{\lambda})^2)}\,/\sqrt{2(\lambda_1^2+\lambda_2^2+\lambda_3^2)}$, where $(\lambda_1,\lambda_2,\lambda_3)$ are eigenvalues of the strain tensor and $\bar{\lambda}$ is the mean diffusivity ($(\lambda_1+\lambda_2+\lambda_3)/3$).

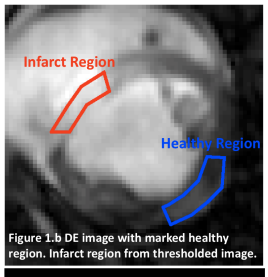

Figure 1.b DE image with marked healthy region. Infarct region from thresholded image.

FA images were registered to the corresponding DE images, and Harp tracking [4] was used to register the FA occurring at end systole with the DE intensities observed on the mid-diastolic geometry. By use of the anterior-septal insertion of the right ventricular wall as a landmark, each image is subdivided into 6 radially spaced segments as shown in Fig 1.a. Mean + 2SD signal intensity of remote healthy segments in DE image is considered as the threshold to compute extent of viability in each sector [5].

RESULTS and DISCUSSION: FA was computed for each animal during all cardiac phases using zHARP. Fig 1.b shows mid-ventricular DE in mid-diastole with marked remote healthy segment and infarcted region, while the latter is computed from the thresholded image as shown in fig 1.c. Fig. 2 plots the intensity pairs (DE, FA) for healthy and infarcted regions with r = -0.89, where FA values are taken from end-systole. This correlation provides a threshold (FA = 0.3) for classification of tissue in FA images. End-systolic FA and thresholded image is shown in fig 4. Percentage of infarction defined as area of infarction divided by total area of myocardium is 0.1479 in end-systolic FA and 0.1523 in mid-diastolic DE image. Considering incompressibility property of myocardial tissue, extent of infarction is comparable in both measures. For healthy and infarcted regions, mean and SD of principal strain values as well as FA is computed and shown in fig. 3 within one cardiac cycle. Separation of these tissue types is evident in all data representations during systole when the heart is compressed and tensors are anisotropic. The low mean ratio of principal values in infarcted region (λ_1/λ_3 = 1.30 and λ_2/λ_3 = 1.13) as opposed to healthy region (λ_1/λ_3 = 2.13 and λ_2/λ_3 = 1.26) at end-systole, when the heart is most contracted, confirms that tensors are substantially less anisotropic in infarcted region. Tissue in this region is not elongated nor compressed in any directions and thus has a smaller FA compared to healthy region that differs markedly from zero.

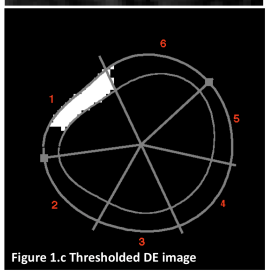

Figure 1.c Thresholded DE image

CONCLUSION: Preoperative evaluation of myocardial viability with current imaging modalities continues to be suboptimal. Traditional methods involve contrast agents and are limited to qualitative estimation of viability. FA is an intuitive and informative measure of strain tensors that encompasses 3D information into a simplified index and shows promise in classification of healthy and infarcted tissue.

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Figure 4.a end-systolic FA image

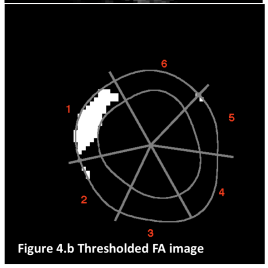

Figure 4.b Thresholded FA image

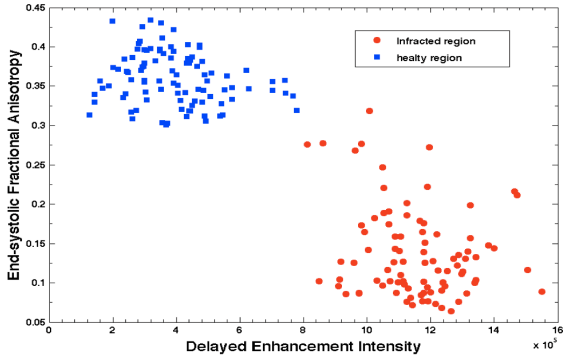

Figure.2 (DE,FA) pairs for two regions with r = -0.89

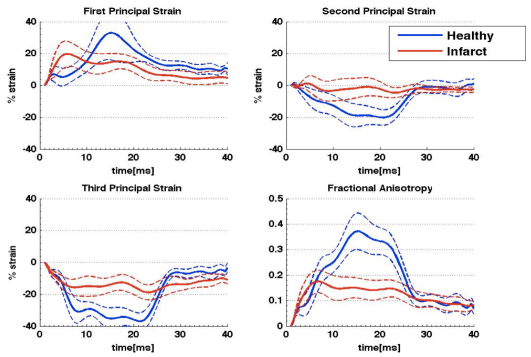

Figure.3 mean±SD for two regions within one cardiac cycle