COMPARISON OF METHODS FOR THE ANALYSIS OF PHASE SENSITIVE INVERSION RECOVERY IMAGES IN THE ASSESSMENT OF MYOCARDIAL INFARCTION

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Introduction: Phase sensitive inversion recovery (PSIR) is a well established method of delineating myocardial scar [1-4]. Parameters such as the relative scar area, transmurality and scar cohesion help to discriminate between myocardial infarction or diffuse fibrosis among others [5]. Quantification of scar volume has been traditionally based on an empirical simple intensity threshold of more than 2 or 3 standard deviations (2SD, 3SD) above the mean of the remote healthy myocardial intensity [6-9]. These techniques require a supervised normal myocardial area selection and may not be sufficiently accurate [10]. There are a few works proposing alternative algorithms that require no user intervention [10, 11]. However, all of these methods have only been applied to 2D image datasets. Recently, navigator-gated 3D PSIR has become possible, yielding images with higher resolution [2]. However, the use of automated myocardial scar volume quantification techniques applied to 3D PSIR has not been evaluated. We compare different scar segmentation methods applied to 2D and 3D PSIR images from swine with myocardial infarction (MI).

Methods: ***MRI*:** Under IACUC-approved protocol, swine (*N=3*, weight ~75-125 lbs) were imaged 3 days to 14 weeks post MI in an Achieva 3T TX system (Philips Healthcare, Best, The Netherlands) using a 32-channel cardiac array(InVivo, Gainsville FL). High-resolution 2D breath hold (2D-BH) and free-breathing 3D navigator-gated PSIR images (3D-FB) [2] were acquired for each animal. Typical imaging parameters for the T_1-weighted 2D spoiled gradient echo scans were: TR/TE = 5.3/2.6 ms, TFE factor 16, 15x5 mm contiguous slices, 250x180 FOV with 2 averages, 200x144 matrix yielding a resolution of 1.25^2 mm^2 in plane, interpolated to 0.98^2 mm^2, in 36 heartbeats. Typical imaging parameters for the 3D sequence (where different) were: TR/TE = 5.5/2.7 ms, 59x3mm slices, 250x238 FOV, 252x197 matrix yielding a resolution of 1.01x1.21 mm^2 interpolated to 0.75^2 mm^2 in ~6 min prescribed scan time. Swine were imaged 3, 5 days and 14 weeks after MI respectively, so time course in MI tissue evolution can also be appreciated in this study. ***Image Segmentation:*** First, manual segmentation of epicardial and endocardial borders was performed in all the slices, avoiding apex due to excessive partial volume. Then, the current +2SD scar thresholding technique was compared to two other methods: a Gaussian Mixture Model (GMM) fitting [11] and the Otsu algorithm [12], both followed by a post processing based on [10]. *Thresholding based on GMM:* A statistical analysis of the populations of voxels within the myocardial contours was made by fitting a Gaussian Mixture Model. The initial segmentation threshold was chosen to be the value that minimizes the overlapping error between both Gaussians (fig. 1A). *Thresholding based on the Otsu method:* An optimal threshold is selected by a discriminant criterion that maximizes the separability of the resultant classes in gray levels. *Post processing (PP):* Segmentations from both GMM and Otsu methods were post processed (GMM+PP, Otsu+PP) as follows: isolated regions with a mass of tissue smaller than 0.1 g (assuming myocardial density of 1.05 g/cm^3) [10] were localized by using a 26-neighbours connectivity and removed. Dark regions of microvascular obstruction (MVO) were classified as infarct if borders were completely surrounded by either endocardial, epicardial or scar pixels. *Analysis:* Expert manual contouring of the scar performed in all the slices in both (3D-FB) and (2D-BH) scans was used as the gold standard. Comparisons were performed based on percent of scar in left ventricle (% of LV), Jaccard similarity coefficients (a measure of similarity between sets, measured as intersection/union) [13] and mean MI surface distances (fig. 1 B,C,D). Image processing and analysis was done in MATLAB.

Results and Conclusions: The scar volumes obtained from 3D-FB scans represent a smoother surface than 2D-BH with more details and subtle features of the scar, as shown by the iso-surfaces in fig. 3. Analysis of performance by method revealed that, both GMM+PP and Otsu+PP were significantly different ($p<0.05$) with respect to +2SD regarding Jaccard values and surface distances. The standard +2SD method had poorer performance and overestimated infarct sizes in all the cases. Otsu+PP and GMM+PP behaved similarly, showing the importance of an optimum threshold selection and the post-processing step in order to remove isolated regions and include MVO (fig. 2). Average errors for the different animals show a reduction in 3D-FB error with respect to 2D-BH in most cases (fig. 1E). However, in animals with high MVO (fig.1D-Case2) automatic methods produced an underestimation in 3D-FB due to a misclassification of the MVO. Further studies are guaranteed to improve these results. In general, factors that can lead to errors are partial volume errors, imperfect manual myocardial segmentation, MVO misclassification and bright imaging artifacts due to navigator gating, all of which can be taken into account during post-processing.

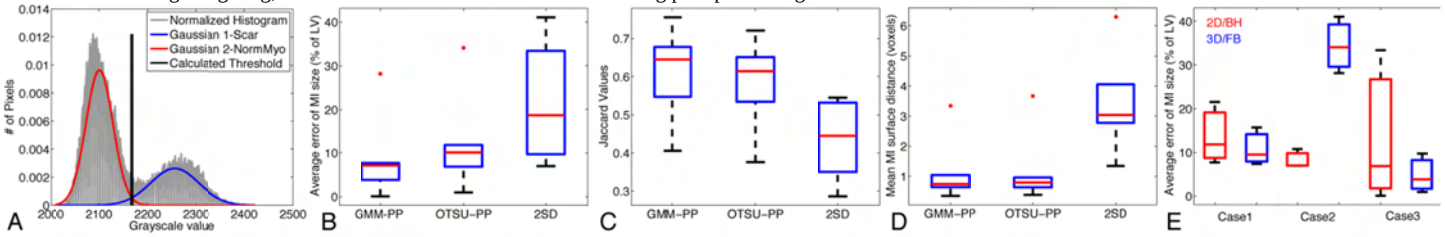

Fig. 1 Histogram and GMM results for a 3D PSIR acquisition (A). Average Error of MI size (B), Jaccard Overlap Values (C) and mean MI surface distances (D) for different methods. Average Error of MI size in 3D-FB and 2D-BH acquisition for the three animals (Case1, 2 and 3)(E) .

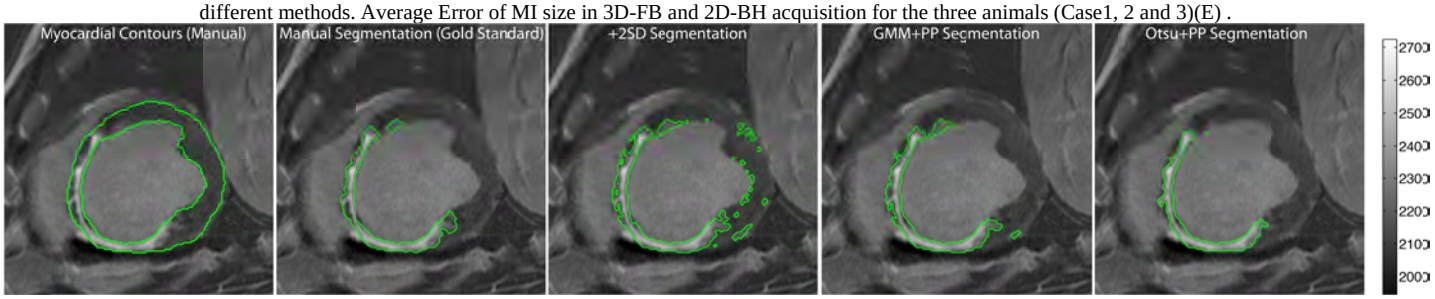

Fig. 2 Myocardial contours and Gold Standard Scar compared to scar segmentations from different methods using data from a 3D PSIR dataset.

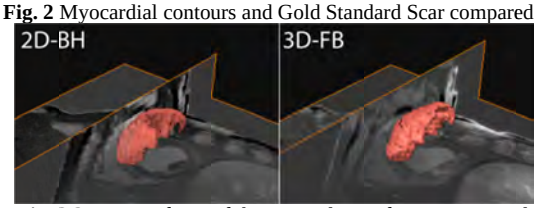

Fig. 3 3D Iso-surfaces of the scar volumes from 2D BH and 3D FB acquisitions based on results from GMM+PP.

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