Robust segmentation and classification of heterogeneous myocardial infarct zones

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Introduction: Heterogeneous myocardial infarct (tissue with a mixture of healthy myocardium and infarct) can lead to ventricular arrhythmias and sudden cardiac death[1]. This heterogeneity, or "gray zone", as detected by delayed enhancement cardiac MRI has been shown to correlate with all-cause post-infarct mortality[2] and inducibility for ventricular tachycardia[3]. However, the delineation of the infarct core and gray zone relies on the standard deviation or peak value of signal intensities (SI) in remote, healthy myocardium, and an arbitrary selection of signal intensity cut-off values. Conventional delayed enhancement images generally have low SNR; random noise, and the position of the ROI used for the remote myocardium may greatly influence the size of the gray zone. Additionally, manual endocardial contours are drawn to segment out the blood pool; in some patients, this can be quite difficult as the infarct and blood pool can have similar SIs. Such inherent variability will reduce the potential utility of grey zone measures. Recently, a new method using an inversion-recovery SSFP (IR-SSFP) sequence has been described to produce infarct-enhanced images at multiple inversion times in a single breath-hold[4]. Image analysis and clustering tools were developed to automatically segment and define the infarct core, gray zone, healthy myocardium, and blood using parameter maps derived from the IR-SSFP images which should better reflect the underlying anatomy and physiology. These tissue classification results were compared to the results using the two conventional definitions of gray zone.

Methods: Six patients undergoing cardiac viability MR scans were included in this study. Short axis delayed enhancement images were acquired on a GE 1.5 T Signa Excite system using a conventional inversion-recovery gradient echo (IR-GRE) sequence and the IR-SSFP sequence. Both sequences were acquired at a resolution of 1.8 x 1.8 x 8 mm over a 32-cm FOV; IR-GRE used a TR/TE = 6.6/3.1 ms and FA = 20^0 while IR-SSFP used a TR/TE = 2.7/1.3 ms, FA = 45^0 and views per segment = 16. IR-GRE produces a single infarct-enhanced image where the signal from healthy myocardium is nulled. ROIs in the remote myocardium were drawn for each imaging slice. For the "peak SI" method[3], the infarct core was defined as any SI above 50% of the peak infarct SI; the gray zone was defined as any SI above the peak SI of the remote region but below 50% of the peak infarct SI. For the "standard deviation" method[2], the infarct core was defined as any SI greater than three standard deviations (and the gray zone between two and three standard deviations) above the remote region mean SI. Multiple remote ROIs were drawn for each image to test the variability of the size of the gray zone. The blood pool was manually segmented out to avoid counting blood pixels as infarct. The IR-SSFP sequence produces 20 images each at a different inversion time. The first eight images occur in diastole and thus have minimal motion; weighted non-linear regression is used to fit each pixel to the signal recovery equation: $SI\ (time\ ) = SS\ [1 - 2\exp(\ -time\ /T_1{}^*)\ ]$, where the fitted parameters are SS (the steady-state plateau) and T_1* (the apparent longitudinal relaxation) (Fig 1D-E). Scatter plots of T_1* versus SS (Fig 1F) are then used as the input to an automated clustering algorithm using the Gustafson-Kessel modification of the fuzzy C-means algorithm[4]. The clustering algorithm automatically segments infarct, healthy myocardium, and blood. Using this fuzzy clustering algorithm, each pixel is assigned a probability of belonging to each cluster: pixels having a probability greater than 75% for belonging to infarct or myocardium were classified as infarct core and healthy myocardium, respectively. Pixels with probabilities between 25-75% for both infarct and myocardium were labelled as the infarct gray zone.

Results & Discussion: Results in a patient using all three methods for defining the infarct core and gray zone are shown in Fig 1. This example illustrates the difficulty encountered when the SI of blood and infarct is similar in the IR-GRE image (Fig 1A) – the manual contour of the blood pool determines whether many of the pixels are blood or infarct. The blood pool can be easily visualized in the T_1* and SS maps (Fig 1D-E), and the clustering results (Fig 1F) clearly delineate the infarct-blood boundary (Fig 1G). Using the SNRs from acquired images, simulations show that the average variability in gray zone size due to the inherent image noise is 19% for the peak SI method and 26% for the standard deviation method. Differences in the location of the remote ROI can add an additional 10% variability. Noise in the IR-SSFP images results in a variability in gray zone sizes of 4%. Absolute comparisons of the core and gray zone sizes are difficult to interpret because all three methods depend on arbitrarily chosen cut-off values or probabilities. Using the cut-off values described in the Methods section, the IR-SSFP analysis tended to detect larger overall infarcts (core plus gray zone) than the peak SI or standard deviation methods. Compared to the IR-SSFP method, the peak SI method (Fig 1B) tended to predict larger gray zones and smaller areas of infarct core, while the standard deviation method (Fig 1C) predicted extremely small gray zones and thus much larger infarct cores.

Summary and Conclusions: We have developed new image analysis tools to segment the infarct core, gray zone, healthy myocardium and blood using IR-SSFP images. The robustness and repeatability of this method is superior to conventional methods of gray zone detection, reducing the number of patients needed to establish a statistically significant relationship between gray zone and ventricular tachycardia. Further studies are planned to study whether this analysis yields a more powerful predictor for ventricular arrhythmias.

References:
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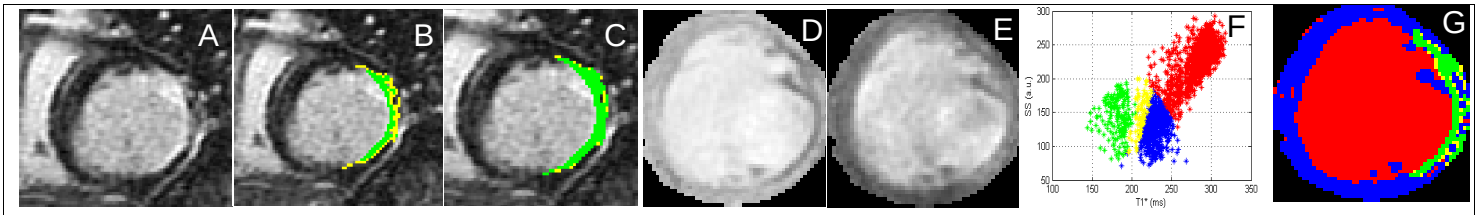

Fig 1. IR-GRE image (A) with corresponding infarct core (green) and gray zone (yellow) using the "peak" method (B) and the "standard deviation" method (C). The IR-SSFP images are used to create parameter maps of T_1* (D) and SS (E), and the scatter plot of T_1* versus SS (F) is used as the input to a fuzzy clustering algorithm that segments out the infarct core (green), gray zone (yellow), healthy myocardium (blue) and blood (red) (G).