Computer Quantification of Myocardial Infarction on Contrast Enhanced Magnetic Resonance Imaging

L-Y. Hsu[1], P. Kellman[1], A. Natanzon[1], A. H. Aletras[1], A. E. Arai[1]

[1]Laboratory of Cardiac Energetics, National Heart Lung and Blood Institue, National Institutes of Hea, Bethesda, MD, United States

INTRODUCTION

Gadolinium delayed enhancement MRI accurately depicts the area of myocardial infarction (MI) when performed at high resolution. Although a high correlation between ex vivo imaging and triphenyltetrazolium chloride (TTC) images has been shown [1], quantitative validation at the resolution used in vivo against TTC has not been studied with these techniques. Segmentation of myocardial infarction on MR images has been performed manually by expert readers and with fixed thresholding. Although fixed threshold techniques reduce inter- or intra-observer variability, they lack robustness due to use of empirical thresholds. We aimed to develop a computer algorithm that objectifies in vivo MI measurements and can be generalized to different MR reconstruction schemes, i.e. magnitude and phase-sensitive. The performance of the algorithm was evaluated using both reconstruction methods and compared to the TTC gold standard.

MATERIAL AND METHODS

MRI scans were performed on 7 mongrel dogs imaged on a 1.5T GE scanner approximately 20 minutes following administration of Gd-DTPA. Myocardial infarction was induced by a 90 minute occlusion followed by reperfusion. Typical imaging parameters achieved in vivo spatial resolution of 1.1x1.8x8.0 mm. Both magnitude and phase-sensitive inversion recovery [2] reconstructions were performed. A reference image was also obtained at a small flip angle (proton density weighted) to measure the surface coil signal variation. Both magnitude and phase-sensitive images were processed using this reference image for intensity correction. Histopathology of the infarct size was confirmed in all animals with TTC staining and photographed at 4 mm intervals. Images of TTC were manually traced to define normal and infarcted regions, and matched with MR based on anatomic landmarks (26 slices). In all MR images, the contours of epicardium and endocardium were first traced manually. The computer algorithm then applied three fully-automated steps to classify infarct and normal tissues in multiple slices [3]. (1) Initial thresholding: based on a two standard deviation thresholding assuming the normal myocardium signal is approximately Gaussian distributed and within two standard deviations of the average intensity. (2) Region based classification: 3D image processing techniques to exclude false positive areas such as small bright pixel blobs that are not contiguous with transmural or subendocardial bright regions. (3) Contour delineation: a full width at half maximum (FWHM) thresholding to account for partial volume blurring and to define the MI boundary in the myocardium. In delayed enhancement imaging, the normal myocardial signal is optimally nulled using the proper inversion recovery time and thus contains noise only. For phase-sensitive reconstruction, the intensity of the normal myocardium is estimated from the peak value of the intensity histogram since the mean value is unbiased. For magnitude imaging, a value of zero was used to define the normal myocardium signal intensity, on the assumption the inversion time was correctly selected to null normal myocardium.

RESULTS

The accuracy of infarct size determination is reported in units of percentage infarct of the left ventricle myocardial area. Figure 1 shows the correlation and Bland Altman plots of infarct size between TTC, as a gold standard, and MRI. Both magnitude and phase-sensitive imaging show good correlations and Bland Altman analysis confirms no consistent bias as a function of infarct size exists. Figure 2 shows the effect of varying the intensity threshold in the final contour delineation step. The minimum percentage error of MI size occurs when the final contouring threshold is set at 50% (FWHM). Use of lower thresholds systematically overestimated infarct size while higher thresholds underestimated infarct size (figure 2). The average error in infarct size determination was less than 1.0% for both reconstruction techniques.

DISCUSSION

The proposed algorithm, which combines surface coil intensity correction, noise estimation, image feature analysis, and region contouring, accurately quantifies the MI size despite significant partial volume effects. The method was effective for both magnitude and phase-sensitive imaging when normal myocardium is properly nulled. It could also potentially be exploited with phase-sensitive image reconstruction over a relatively wide range of inversion recovery times [2]. This computer-aided methodology should be useful for serial infarct sizing studies where accuracy and repeatability are essential.

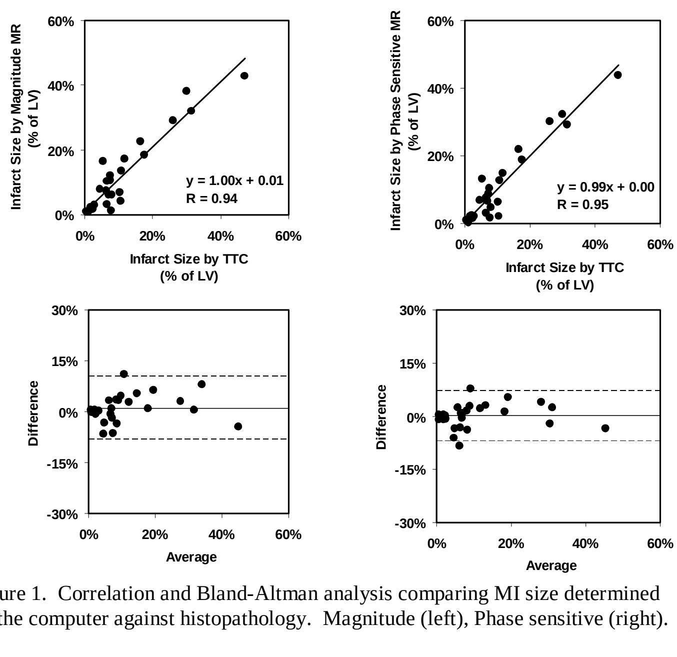

Figure 1. Correlation and Bland-Altman analysis comparing MI size determined by the computer against histopathology. Magnitude (left), Phase sensitive (right).

REFERENCE

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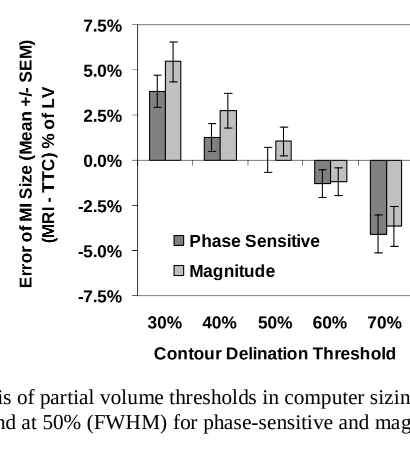

Figure 2. Analysis of partial volume thresholds in computer sizing. The optimal settings were found at 50% (FWHM) for phase-sensitive and magnitude imaging.