Percent Infarct Mapping, a Novel In Vivo Tool for Determining Myocardial Viability, is More Accurate than Delayed Enhancement

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INTRODUCTION Contrast enhanced MRI has the potential to detect viability following myocardial infarction. Contrary to signal intensity (SI), the longitudinal relaxation rate enhancement (ΔR1) is an intrinsic parameter linearly proportional to the concentration of contrast agent (CA) in any given voxel. Determining ΔR1 voxel-by-voxel after the administration of an infarct-avid CA, therefore, allows the determination of the per-voxel percentage of infarcted tissue. In this manner the 3D information hidden in 2D MRI images can be utilized to detect the distribution of infarcted tissue with great accuracy. We propose that a 3D ΔR1 map be generated from which a percent infarct map (PIM) can be created for the entire left ventricle (LV). The feasibility of this method is demonstrated here in an in vivo closed-chest model of reperfused infarction, using an infarct-avid, persistent CA (PCA). In this work, the agreement with TTC staining of the PIM method using the PCA, Gd(ABE-DTTA), is compared to that of the "delayed enhancement" (DE) method using Gd(DTPA).

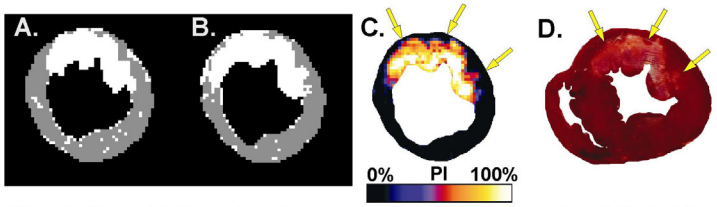

Figure 1. Equatorial short axis post-processed MRI images are shown in an infarcted dog heart. **A.** Thresholded DE image with Gd(DTPA). **B.** Thresholded DE image with Gd(ABE-DTTA)(DE-PCA). **C.** Voxel by voxel Percent Infarct MAP (PIM). Percent Infarct value (PI) is shown on a color scale in the form of 0-100% of infarcted tissue per voxel. **D.** Corresponding TTC-stained photo. Note the excellent correspondence between PIM and TTC staining regarding infarct localization. While TTC staining only shows the surface of a slice, PIM shows in-depth information about the tissue. The tortuous morphology of the infarct can be seen in the TTC photo in the regions marked with arrows. In these regions infarcted and viable tissue are mixed, the infarct is patchy. DE is unable to differentiate patchy infarct from solid infarct as all enhanced voxels are presented 100% necrotic. PIM, however, visualizes the patchyness of the infarct and it quantifies each voxel individually. Thus, PIM is a more realistic representation of a tortuous infarct and yields more accurate measurement of infarct size.

METHODS In closed-chest, LAD-, or LCx-occluded (180min) dogs (n=6), forty-eight hours following reperfusion DE imaging was carried out using 0.2mmol/kg Gd(DTPA) as described in recent literature.[1] A persistent CA (PCA), Gd(ABE-DTTA) (0.05mmol/kg), was administered immediately following DE imaging.[2] Short axis inversion-recovery (IR) images were generated with varying inversion time (TI) 24, and, 48 hours following PCA administration covering the left ventricle (LV). Imaging parameters were FOV=300mm, matrix=256x256, slice=10mm, flip angle=25°, echo time=3.32ms, VPS=16, recycle time=1800-2700 ms (constant throughout an individual T1 mapping experiment). Nine TIs were used in the range of 200-1200ms.[3] T1 was calculated from the TI dependence of the SI, using bi-exponential least-squares curve-fitting. R1, ΔR1 and percent infarct values were calculated in a voxel-by-voxel manner (Figure 1). The PCA enhanced IR image at 48h (DE-PCA), where remote viable regions were nulled (TI=500ms), was also analyzed exactly as the Gd(DTPA)-enhanced DE images to compare the two agents under the same conditions. Following the last imaging session in vivo TTC staining was carried out and the animals were euthanized. Hearts were then excised, rinsed with saline, frozen in -80C ethanol, breadsliced and photographed. Total LV myocardial mass (TMM), total infarct mass (TIM), infarction fraction (IF), percent infarct per slice (PIS) and infarct mass per slice (IMS) were calculated from DE and DE-PCA images, from PIMs at 24h and 48h, and from TTC-stained slices. MRI image analysis was semiautomated. The only manual input was tracing the endo- and epicardial contours in all slices. Remote SI+2SD was used for thresholding DE images.

Table 1.

PEARSON correlation coefficient with TTC	DE with Gd(DTPA)	PIM at 24h	PIM at 48h	DE with Gd(ABE-DTTA)
PIS	0.80	0.93	0.95	0.77
IMS	0.80	0.91	0.91	0.84

RESULTS No significant difference was found among TMM values obtained using different MRI methods and TTC ($p>0.05$). Significant ($p<0.01$ for all) pairwise correlations were obtained for IMS and PIS determined using DE or PIM in any given slice vs. those from corresponding TTC-stained slices (Table 1). Average errors in the measurements using the four methods are shown in Table 2. The errors obtained with the PIM method at both time points were minimal, and statistically smaller ($p<0.05$) from those obtained with DE using either agent but not different from each other. Average differences between PIMs at 24h and 48h were 0.12±0.46g and 1.15±3.5% for IMS and PIS, respectively. No statistically significant difference was found between DE results obtained using Gd(DTPA) or Gd(ABE-DTTA).

Table 2.

Average difference from TTC (±SD)	DE with Gd(DTPA)	PIM 24h	PIM 48h	DE with Gd(ABE-DTTA)
PIS (%)	31.97 ± 17.69	-0.23 ± 5.84	-1.12 ± 4.97	29.90 ± 18.27
IMS (g)	3.95 ± 1.90	0.16 ± 0.68	0.05 ± 0.66	3.30 ± 1.64
IF (%)	28.88 ± 6.05	1.59 ± 1.65	0.21 ± 1.88	25.02 ± 4.91
TIM (g)	21.43 ± 4.96	1.01 ± 0.91	0.30 ± 0.99	17.44 ± 3.10

CONCLUSIONS Infarct size was overestimated using in vivo DE with Gd(DTPA) in agreement with other investigators' findings.[4-7] Gd(ABE-DTTA) highlighted the same regions as Gd(DTPA), and yielded similar results when single-TI IR images were processed as DE images. Using this infarct-avid PCA, however, high-resolution PIMs could be generated based on T1-maps. In this manner, the mixed nature (infarct mixed with viable tissue) of voxels can be revealed and taken into consideration when assessing regional or global infarct mass. PIM is highly reproducible and is more accurate for determining myocardial viability than DE. The image post-processing method of PIM may also be used in the future with fast-tissue kinetics contrast agents, and fast T1-mapping techniques.

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