

3D DETERMINATION OF AREA-AT-RISK IN ACUTE MYOCARDIAL INFARCTION

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Introduction: The area of myocardium at risk (AAR) is defined as hypoperfused myocardium at the time of an ischemic episode¹, such as acute myocardial infarction (MI). To evaluate therapeutic procedures and drugs aimed at modulating infarct size, it is essential to know AAR before reperfusion to assess salvaged myocardium as AAR minus final infarct size. Late Gadolinium enhancement (LGE)² and phase sensitive inversion recovery (PSIR)³ are well-established methods of delineating infarction. T₂-weighted imaging is also an established method for visualizing myocardial edema⁴ though it has some drawbacks such as signal heterogeneity due to phased array coils, confounding residual signals from slow-moving blood and subjective image interpretation.^{5,6} Quantitative T₂ mapping has been shown to solve these issues.⁶⁻⁸ When combined with respiratory navigators, both 3D LGE with PSIR⁹ and 3D T₂ mapping can provide high-resolution whole-heart coverage. This work shows that the combination of T₂ maps and PSIR images yields high-resolution whole-heart AAR determination possible.

Methods: *MRI:* Under IACUC-approved protocol, in two swine, the mid-left anterior descending coronary artery was occluded for 120 min using a balloon angioplasty catheter (2.7 Fr) to create an MI. Imaging took place 3 days and 8 days post MI using an Achieva 3T TX system (Philips Healthcare, Best, Netherlands) and a 32-channel cardiac phased array (InVivo, Gainesville FL). T₂-mapping⁸ of the ventricles was carried out before the injection of contrast agent (0.2 mmol/kg, Magnevist). Three interleaved volumes were acquired with T₂Prep TE = 0, 25, 45ms. (Imaging parameters: TR/TE 4/1.2ms, flip angle 18°, diastolic window 48.6ms, FOV 250×240×90mm³, voxel size 1.25×1.25×5.0mm³ interpolated to 0.98×0.98×2.5mm³, prescribed scan time 7min 15s with respiratory navigator gating efficiency of about 30-50%). Post-contrast independently navigated 3D PSIR images⁹ were acquired 30min post infusion. (Imaging parameters: TR/TE 5.6/2.7ms, flip angle 18°, diastolic window 67.7ms, FOV 250×238×90mm³, voxel size 0.99×1.27×3.0mm³ interpolated to 0.74×0.74×1.5mm³). Both 3D sequences were respiratory navigator gated.

Post processing: 3D T₂ maps were calculated per voxel using linear regression with the three T₂Prep volumes. Rigid registration was performed (inside the framework of ITK) on PSIR images against T₂ maps. Registration parameters were chosen taking into account image features (mutual information metric, gradient-based optimization and linear interpolation). The left ventricle (LV) was manually segmented slice by slice on T₂ maps, with papillary muscle and epicardial / endocardial boundaries excluded to avoid partial volume effects. Slices within 10mm of the apex were excluded to avoid the inaccurate segmentation due to excessive partial volume averaging. Endo- and epicardial contours were superimposed onto PSIR images to verify that the segmented LV was matched in both T₂ maps and PSIR images. On the T₂-maps, 3 ROIs, each containing more than 120 pixels, were used to designate reference normal myocardium and were placed at locations far from MI as identified on PSIR images. The pixels with T₂ values less than 2 standard deviations above/below the mean of the reference myocardium were regarded as normal myocardium. The pixels with T₂ values 2 standard deviations above the mean of the reference myocardium were regarded as edema.⁷ Otsu's method¹⁰ was used to compute a global threshold which maximizes the separability of classes in gray levels to differentiate MI from normal myocardium. Infarct percentage from PSIR and edema from T₂ maps were mapped to 2D using bull's eye plots with 90 radial segments per slice and 23 slices spanning 75 mm in the axial direction. The AAR percentage was calculated from the residual of tissue identified as normal (not MI, not edema, not microvascular obstruction).

Results: Representative PSIR images and T₂ maps from 3 and 8 days post MI are compared in Fig. 1 (a, b, g, h). The infarcted tissue shrinkage and edema absorption were observed. The stack of T₂ maps was plotted in 3D view in Fig. 1 (c, i). 49% of the whole left ventricle was identified as edematous with T₂ values of 58 ± 7 ms in 3 day post MI, the proportion of edema decreased to 41% at 8 days post MI with T₂ value increased to 67 ± 18ms. Areas with elevated T₂ were mainly around infarcted tissue. However, some areas of increased T₂ were observed in the anterior myocardial wall and were likely an artifact and due to the use of gradient echo readouts and T₂*. Normal myocardial T₂ values were (43 ± 3 ms) and (43 ± 3ms) for 3 and 8 days post MI, respectively. 32% of the LV volume was identified as infarct at 3 days and the proportion decreased to 18% 5 days later. The infarct, edema and AAR proportion were mapped onto bull's eye plots in Fig. 1 (d-f, j-l). Some T₂ maps suffered from artifacts in the anterior wall due to field inhomogeneity at the lung-heart-liver interface.

Conclusion: These preliminary results show that the combination of 3D navigator-gated T₂-mapping and PSIR imaging can provide high-resolution whole heart evaluation in acute MI. From these two types of images, the determination of the AAR in 3D could be a robust and quantitative probe for myocardial salvage in MI. Additionally, the time course of injured / damaged tissue due to MI was observed, and the results were similar to those available in the literature.¹¹⁻¹³ However, the high-resolution achievable with 3D imaging and the quantitative nature of the data presented permit a more detailed assessment of the AAR. In this swine model of acute MI, T₂-mapping shows that the area of partial edema at the periphery of the regions detected as MI with PSIR may recover over time (Fig 1e vs. Fig 1k). Though previous work¹⁴ has indicated that the volume of edema peaks ~2-14 days post injury by MI, the imaging resolution and techniques used may not have been sensitive to some of the more subtle changes during the progression after injury. More studies using the presented techniques are warranted to determine the nature of the progression of the peripheral edematous regions.

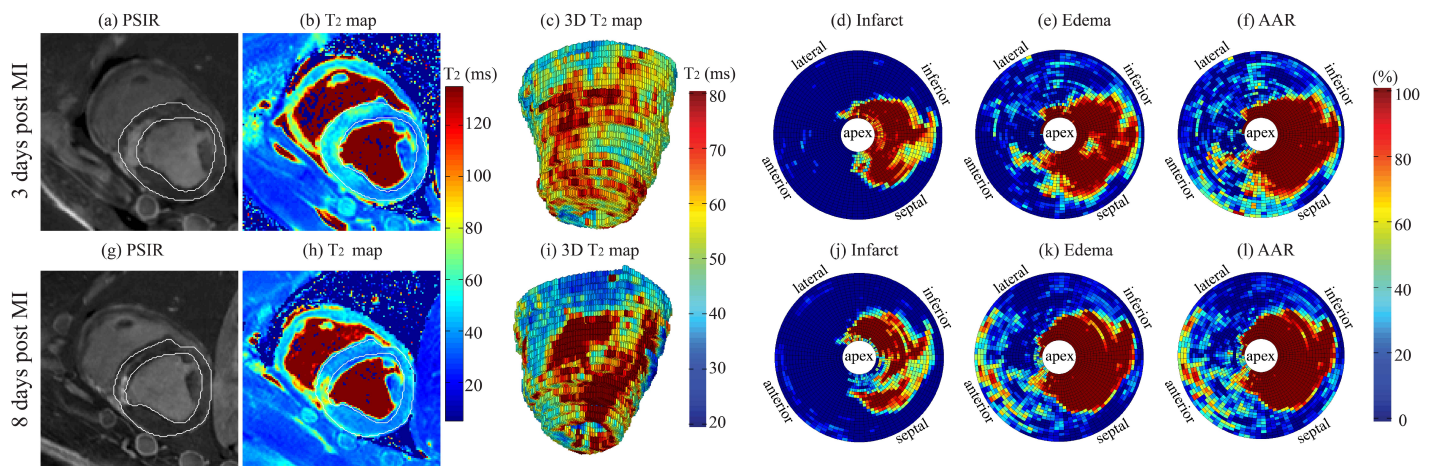


Figure 1: Representative 3D PSIR images and 3D T₂ maps acquired 3 days (top) and 8 days (bottom) post MI. Manually segmented endo- and epicardial contours (white) are superimposed on registered PSIR and T₂-maps (a,b,g,h). The 3D PSIR datasets of T₂-maps can be visualized in 3D view as stacks (c,i), or mapped onto 2D plane in the form of bull's eye plots (d-f,j-l). In the latter plots the scale indicates percent of the original pixels that were considered MI, edema, or AAR. When combined the 3D maps of MI and edema can be used to calculate the AAR (f,l). These plots show a reduction of edema peripheral to the MI from day 3 to day 8.

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References: [1] Aletras et al. Circ 2006 113: 1865; [2] Kim et al. N Engl J Med 2000343:1445; [3] Kellman et al. MRM 2002 47: 372; [4] Simonetti et al. Card Radiol 1996199: 49; [5] Abdel-Aty et al. JMIR 200726: 453; [6] Giri et al. JCMR 2009 11: 56; [7] Verhaert et al. JACC Card Img 2011 4: 269; [8] Ding et al. ISMRM 2011; [9] Lee et al. ISMRM2011; [10] Otsu et al. Automatica 11-285, 1975; [11] Grugre et al. MRM 2011; [12] Rundell et al. ISMRM 2011; [13] Beyers et al. MRM 2011; [14] Friedrich, Nat Rev Cardiol 2010 7: 292