Novel detection of intramyocardial hemorrhage following acute myocardial infarction by T2 mapping

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Introduction: Left ventricular remodeling following acute myocardial infarction (AMI) is associated with significant morbidity, ultimately leading to cardiovascular dysfunction, disability and death. While coronary reperfusion is favorable in terms of myocardial salvage, 'reperfusion injury' (RI) may often present itself as an adverse consequence (1). Intramyocardial hemorrhage is an undesirable component of RI and may occur in ~40% of ST-elevation myocardial infarction (STEMI) cases (2). Hemorrhage may also be an independent predictor of adverse outcomes following AMI and hence, its detection has become a clinical priority. Recently, T2-based sequences have been useful to delineate hemorrhage post-AMI (2). Some investigators have utilized T2 mapping approaches (3,4) that involve fitting signal intensities to an exponential function [M=M0.exp(-t/T2)]. However, the T2 measurements obtained can be confounded by the opposing effects of hemorrhage and edema along with the presence of microvascular obstruction (MVO) in the acute phase of AMI (3). We hypothesized that the M0 term may provide additional information beyond T2 for identifying the hemorrhagic sites. A T2* sequence was also utilized as a reference since T2* is a more specific marker of hemorrhage (5).

Methods: The study involved a porcine model of myocardial infarction (N=6), where the left anterior descending artery (LAD) was occluded for 90 min followed by reperfusion. Imaging was performed on a 3T MRI scanner (MR 750, GE Healthcare) pre-occlusion (healthy control) and at day 2 post-infarction. T2 measurements were performed using a previously validated T2-prepared spiral imaging sequence (3) with the following parameters: 6 ms refocusing interval, sixteen 12.3 ms spirals (3072 points), five TE's (2.9-184.2 ms). The T2* sequence was a multi-echo gradient echo acquisition with 8 echoes (between 1.4 and 15.5 ms) and TR=18.3 ms. Infarct assessment was performed by delayed hyperenhancement (DHE) using an IR-GRE sequence. T2, M0 and T2* maps were obtained by fitting signal intensities at each pixel with an exponential model. The computed values were expressed as mean±standard deviation. Hearts were extracted for histological analysis.

Results: Figures 1 shows DHE images along with T2*, T2 and M0 maps from a representative animal. All animals demonstrated large transmural infarction with MVO (Fig. 1a). At day 2, T2* values in the infarct zone (identified from DHE) were significantly lower than control values (27.8±4.9 vs. 35.8±1.6 ms, p=0.004) indicating the presence of hemorrhage. T2* values within the sites of hemorrhage (arrows in Fig 1b) were found to be even lower (15.7±5.4 ms, p=0.0001). T2 values in the infarct zone were only subtly elevated compared to control values (41.6±2.4 ms vs. 38.2±1.6 ms, p=0.03) and sites of hemorrhage could not be distinctly identified (Fig. 1c). However, the M0 maps demonstrated signal voids (arrows in Fig. 1d) that were spatially correlated with those identified as hemorrhage on T2* maps. Furthermore, T2 values measured within the signal voids on M0 maps were found to be lower than those in the larger infarct zone (38±2.9 ms, p=0.002). Figure 2 shows another example demonstrating the spatial correlation of hemorrhagic regions on T2* (Fig. 2a) and M0 (Fig. 2b) maps along with histological H&E staining identifying hemorrhage within the infarcted myocardium (Fig. 2c); red blood cells can be seen along with inflammatory cells on the magnified section (Fig. 2d)

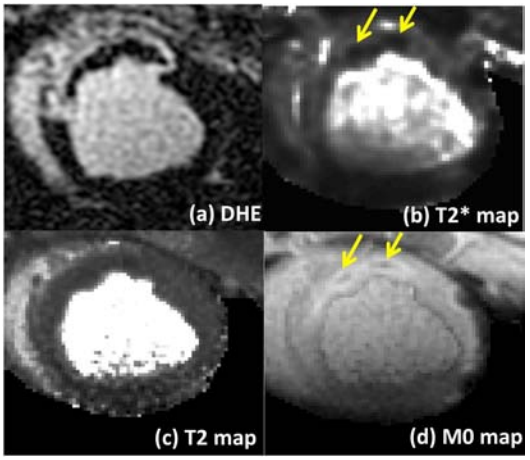

Figure 1: Short axis images from a representative animal showing DHE and T2*, T2 and M0 maps at day 2 post-AMI. Arrows indicate sites of hemorrhage apparent on T2* and M0 maps.

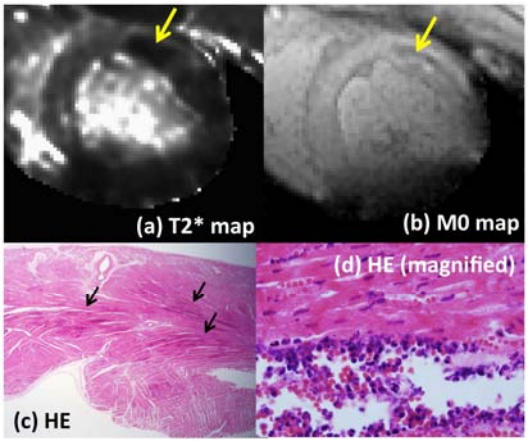

Figure 2: Short axis images from a representative animal showing T2* and M0 maps at day 2 post-AMI along with H&E stains from the infarct zone. Arrows in (a,b) indicate site of hemorrhage apparent on T2* and M0 maps and those in (c,d) indicate bleeding within the tissue.

Discussion: Patients presenting with intramyocardial hemorrhage constitute a high-risk group in clinical AMI, warranting the need to quantify the degree of hemorrhage; relaxometry techniques can be instrumental in this regard. T2 maps can identify hemorrhage as a result of spin dephasing around paramagnetic iron-degradation products of hemoglobin (deoxy-, met-hemoglobin, hemosiderin). However, the presence of edema can nullify this effect by elevating the T2 values in the infarct zone. In contrast, the M0 map, which is typically discarded in the post-processing step, may be important in identifying the extent of hemorrhage. The M0 map is reflective of the short T2* species whose signal is too rapidly lost (signal voids) to be captured by the typical T2 acquisition strategy. In addition, the M0 map is also T1-weighted and may thus help delineate methemoglobin (short T1 species) conversion as well (bright signal in Fig. 1d). Our study demonstrates that T2 and M0 maps together provide complementary information that may potentially be valuable in simultaneously characterizing both the inflammatory and hemorrhagic state of tissue post-AMI.

References:

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