Reperfusion Intramyocardial Hemorrhage Following Acute Myocardial Infarction: Assessment using Magnetic Resonance Susceptibility Weighted High-Pass Filtered (HPF) Phase Imaging

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Introduction: Emergent reperfusion therapy restores blood flow to ischemic left ventricular (LV) myocardium in acute myocardial infarction (AMI). Several studies have shown its benefits in terms of reducing infarct size and improving clinical outcomes. Restoration of blood flow can additionally cause myocardial damage and the phenomenon is termed "reperfusion injury". Reperfusion injury is an independent risk factor and can reduce the benefits of myocardial reperfusion. Intramyocardial hemorrhage represents a feature of severe reperfusion injury and is associated with adverse outcomes and may play a role in reperfusion injury, the healing process and ventricular remodeling. Detection of intramyocardial hemorrhage has been shown with T2-weighted (T2W) and T2*-weighted (T2*W) magnitude images and is associated with microvascular obstruction (MVO). Magnetic resonance image phase is typically discarded and not evaluated with the notable exception being phase contrast angiography. Phase images contain additional magnetic field information on both the macro- and micro-scopic levels about local susceptibility changes between tissues. High-pass filtered (HPF) processing of phase images is routinely used to remove low spatial frequency components of the background field. Susceptibility-weighted images have been shown to be sensitive for the detection of hemosiderin in microbleeds of the brain and therefore we sought to determine whether HPF-phase images would be an effective means of detecting myocardial hemorrhage.

The major aim of this study was to quantitatively investigate LV myocardial HPF-phase in gradient echo images in normal subjects to determine normal ranges as a function of echo delay time (TE) and anatomical position and then compare HPF-phase values in patients with myocardial infarction of varying ages with those normal ranges. Comparison of the HPF-phase technique with other MR imaging techniques will be used to show the feasibility of the detection of myocardial hemorrhage with HPF-phase imaging.

Materials and Methods: Eleven myocardial infarction subjects and 15 age matched healthy control subjects were included for analysis from 44 imaging sessions. These consisted of 15 normal control sessions, 11 AMI sessions at 3 day after infarction, 7 sessions at 30 day after infarction, 5 sessions at 6 months after infarction and 6 sessions at 1 year after infarction. All MR examinations were performed with a 1.5-T MR imager. The comprehensive MR cardiac study consisted of five imaging techniques: 1) left ventricular cine functional, 2) T2-weighted fast spin-echo, 3) multiple gradient recalled-echo, 4) first pass resting perfusion and 5) late gadolinium enhanced infarct imaging. A dark blood double inversion recovery multiple-gradient echo sequence (flip angle = 20 degrees; repetition time, 20 ms; 12 echo times, 2.4-15.5 ms (1.2 ms spacing); in-plane spatial resolution, 2.5 x 1.7 mm2, bandwidth = 2005 Hz/pixel, breath-hold duration=15 heartbeats) was used for T2* weighted and HPF-filtered phase imaging. Raw k-space data were saved to the scanners hard disk and transferred to a personal computer. All images were analyzed off-line with specialized post-processing software. Filtered phase images were reconstructed using Matlab R2009b (Mathworks, Natick, MA) from saved raw data files for both long and short axis images. High-pass filtered phase images for each echo time were reconstructed by first reconstructing a complex low pass image using a 64 point hanning filter and unfiltered complex image. High-pass filtered phase images were then calculated by dividing the low pass filtered image into the unfiltered image and then extracting the phase component. Region-of-interests were drawn on the short axis images (basal, mid-ventricular and apical) for each subject on each of the 16 AHA segments of the left ventricle and mean phase signal was computed for each echo delay time. The mean and standard deviations were calculated and variations across segments were compared using repeated measures two-way ANOVA. Phase values in MI patients were considered abnormal if outside the normal range of mean± 2stdev.

Results: Filtered phase in the control group was small, on average across echo times and patients being zero in all segments with variance significantly increasing with echo time (Fig 1, p<0.001). There was a difference between anatomical segments, with less variation in septal segments (p>0.05) compared to a cyclic variation due to myocardial fat in other segments (p<0.001) (Fig

Fig 1. Normal phase values in 4 of 16 measured anatomical segments. Phase variance was less in all septal segments (P<0.001). There was a consistent cyclic variation due to fat in anterior, inferior and lateral segments.

Fig 2 Two chamber images from a patient with a transmural inferior wall infarct resulting from an RCA occlusion. Myocardial hemorrhage is visualized in HPF-phase images (TE=15.5) and confirmed by quantitative ROI phase analysis (red line) which is plotted with normal ranges (black lines).

2). There were nine patients with transmural infarcts, 6 with MVO and 4 with hemorrhagic infarction detected by phase outside of the normal range for more than two consecutive phase images. Three hemorrhagic infarcts were visualized at 30 days. Phase in hemorrhagic infarcts decreased with echo time, making image contrast greater(Fig 2).

Conclusions: High pass filtered myocardial phase is small and normally varies by anatomical myocardial segment. Myocardial hemorrhage causes a significant phase decrease beyond these normal variations. HPF-phase images represent a quantitative, high quality method for the detection of myocardial hemorrhage without the need for the presence or high q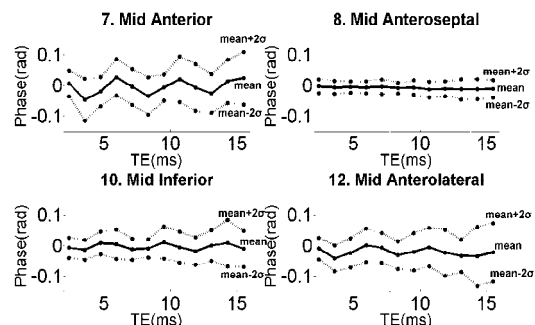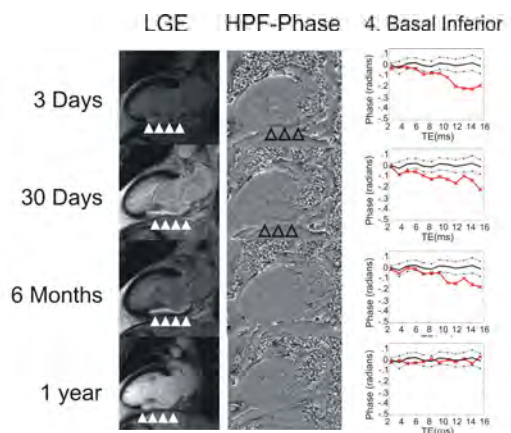uality visualization of myocardial edema.