Spiral T2 quality evaluation in patients with coronary artery disease

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Introduction: T2 has proven to be a valuable contrast mechanism for myocardial characterization because it is a quantitative biomarker of acute and sub-acute inflammatory processes.[1] Clinical integration of T2 relies on T2-weighted black-blood fast-spin echo (FSE) imaging because cardiac-gated imaging is achievable in breath-hold scan times and with useful spatial resolutions. However the information is semi-qualitative and the echo-train readout compromises T2 contrast.[2,3] Furthermore, FSE variability (ie. associated with coil shading) limits sensitivity to grossly abnormal myocardium (ie. T2 elevations of upwards of 80% in edematous infarction[1]) and complicates the interpretation and translation of measurements between short-axis locations, and within and between patient cohorts. For left ventricular evaluation, approximately 7 minutes is required for multi-slice interrogation at a single echo time in a series of breath-held acquisitions (~35 seconds per slice, accounting for scanning, inter-breath-hold recovery, and breath-hold preparation). A magnetization-prepared spiral imaging method, termed T2prep, should improve reproducibility in clinical quantification of myocardial T2 relaxation because variability associated with coil shading is removed.[4] Furthermore, the potential exists for greater time efficiency because a multi-slice acquisition with 2 echo times can be completed within 4 minutes without breath-holds, using free-breathing but respiratory motion-compensated and cardiac-gated scanning. Towards an optimization of T2prep reproducibility for clinical myocardial measurements, this research characterizes T2prep and FSE measurement quality within a patient population with coronary artery disease.

Methods: Nine patients were scanned using a cardiac phased-array coil within a 1.5 T GE Signa as part of a larger cardiac MR study monitoring left ventricular remodeling following percutaneous revascularization of chronic total occlusion. FSE and T2prep scanning covered the left ventricular short-axis as a series of contiguous sections. Black-blood, breath-hold, and cardiac-gated FSE imaging used standard parameters (~3 RR interval repetition time, ~600ms blood nulling delay, 35 x 32cm FOV, 320 x 192 matrix size, 8mm slice thickness, 68ms TE). Myocardial T2prep imaging used an optimized parameter set (echo times of 3.2 and 49.8ms, refocusing interval of 24ms, cardiac gating across 2 heart beats, ten 12.3ms spiral interleaves at a readout bandwidth of 125kHz providing 1.84 mm in-plane resolution over a 35cm field-of-view, 2 nex)[4]. Respiratory motion compensation used the Diminishing Variance Algorithm with the respiratory belt and an overscan factor of 3, so that a complete data set is acquired with corresponding respiratory positions and outlier spiral interleaves are iteratively replaced until the total scan time is increased 3-fold.

Data analysis restricted evaluation to viable myocardium with normal systolic function (>3mm shortening) within each of 3 slices (below the left ventricular outflow tract; mid-myocardial, 1cm above the apex). Initial analysis calculated the mean and variability (2σ) of global per subject characteristics (FSE: per voxel mean and standard deviation SNR; T2prep: per voxel mean and standard deviation SNR and T2). Phased-array coil SNR was calculated as per the methods of Constantinides[5]. The lower 95% confidence intervals of global FSE and T2prep per voxel SNRs defined the minimal usable region-of-interest (ROImin) volume for thermal noise insensitive measurements, because the per ROI SNR is elevated from the per voxel SNR by the square root of the number of independent voxels. The residual parameter variability (defined as 2σ of measurements across multiple ROImin) is thus a probe of 'physiological noise' and residual biases that may have local effect, and defines the threshold for confident detection of significant parameter differences. For each subject, up to 8 regularly-spaced ROImin were considered for each slice.

Results: 8 patients demonstrated viable myocardium with significant segmental shortening (> 3mm) and 1 patient demonstrated segmental wall motion abnormalities and delayed hyperenhancement consistent with previous myocardial infarction. No patient presented with edema on FSE or T2prep images. Representative T2prep maps and FSE images are illustrated below. At an echo time of 68ms, FSE scanning provided an average SNR of 32±12 (2σ) that suggests that global signal changes must be greater than 38% for confident detection of FSE signal differences. T2 mapping provided a mean global SNR of 92±30 and 36±13 (2σ) at echo times of 3.2 and 49.8ms, and a mean global T2 of 50±7ms (2σ). Thus the confident detection threshold is 14% for global T2 and 36% for late TE T2prep. Based on Monte Carlo simulation, reduction of thermal noise variability (2σ) to 3% is achieved when the per ROI SNR is 67 for FSE and 200 for T2. At the lower 95% confidence intervals of the SNRs, noise targets are attained using ROImin of at least 11 independent voxels, or a ROImin volume of 0.16cc for FSE (47 voxels, extrapolated to 512x512) and 0.3cc for T2prep. For FSE, the mean residual variabilities (2σ) across basal, mid, and apical slices ranged from 45 to 56% (61, 53, and 61 ROIs across 9 subjects). For T2prep, the associated mean residual variabilities (2σ) were 18, 19, and 24% which are consistent with prior characterization of spatial T2prep variability within a cohort of healthy volunteers using a single-slice methodology.[4]

Summary: In the absence of gross relaxation fluctuations, current clinical myocardial FSE scanning is useful only to delineate cardiac margins. When thermal noise is minimized and assuming mean myocardial T2 of 50ms, the residual 38% global reproducibility at a TE of 68ms prevents discrimination of T2 values between 37 and 66ms, while the residual 50% regional reproducibility prevents discrimination of T2 values between 33 and 71ms. Coil shading and compromised blood nulling in apical slices appear to be primary sources of FSE signal variability. The corresponding detection limits for T2prep are 43 and 57ms for global measurements and 40 and 60ms for regional measurements. Thus, quantitative T2prep mapping reduces variability towards physiological noise levels, providing more reproducible measurements with the potential for faster scan times at minor cost to spatial resolution and ROImin. Iterative testing in future cohorts should target spiral image fidelity (ie. equivalent in-plane resolution as FSE, shorter spiral durations to alleviate off-resonance blurring near coronary veins and the heart-lung interface).

References: 1) Foltz, MRM, 2006**; 2)** Abdel-Aty, JMRI, 2007; **3)** Listerud, Magn Reson Q, 1992; **4)** Foltz, MRM, 2003; **5)** Constantinides, MRM, 1997.

Figure: Basal, mid-myocardial, and apical short-axis T2 maps windowed and leveled between 0 and 100ms (a-c) and FSE images (d-f). Mid-ventricular nulling in T2 maps are consequent of ventricular blood nulling in multi-slice T2prep acquisitions.