Three-dimensional local-look spectroscopic imaging of the heart

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Introduction

The study of changes in energy storage and utilization by means of cardiac spectroscopy in ischemic, diabetic and failing hearts has been a vivid area of research [1, 2]. Using proton spectroscopy, myocardial creatine [3] and triglyceride [4] content could be assessed in the beating heart. In order to compensate for respiratory and cardiac motion, navigator gated and cardiac triggered single-voxel techniques have been developed [5, 6]. To avoid signal contamination from epicardial fat the volume of interest is usually placed in the septal wall. While this technique is only suitable for studying global changes [7], spectroscopic imaging techniques are needed to detect local changes in metabolism. Recently, navigator gated and cardiac triggered 2D Echo-Planar Spectroscopic Imaging (EPSI) has been introduced [8]. However, only single-slice data composed of multiple signal averages have been presented. In the present work, we propose a 3D extension of cardiac EPSI employing k_z phase-encoding instead of averaging to increase the volumetric coverage while maintaining the same signal-to-noise ratio per unit time (SNR_t). Challenges associated with 3D EPSI in relation to the larger volume of interest potentially compromising shimming and water suppression are discussed.

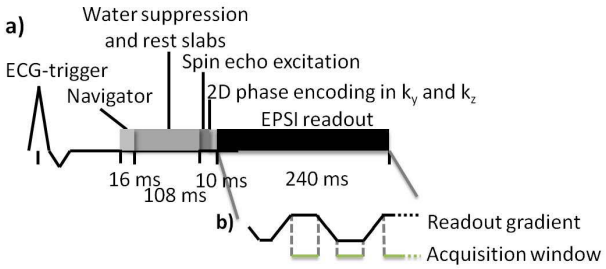

Figure 1: Schematic of the 3D local-look navigator gated EPSI sequence a). Spatial encoding in k_y and k_z is performed using phase encoding after spin echo excitation, prior to k_x- and spectral encoding using echo-planar readouts b).

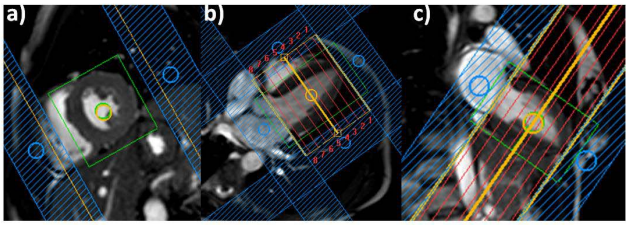

Figure 2: Measured volume (yellow box) indicated in short-axis (a), four chamber (b) and right anterior oblique views (c). Slice positions are indicated in red, the volume used for shimming is indicated in green. Four rest slabs placed orthogonal to the two phase encoding directions are indicated in blue.

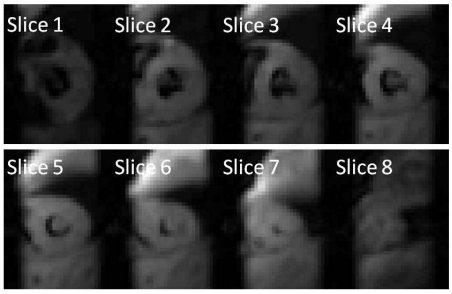

Figure 3: Eight out of twelve encoded slices within the field of excitation from a non-water suppressed 3D EPSI data set. There are no visible motion artifacts.

Methods

Local-look navigator gated and cardiac triggered spin echo 3D EPSI (Figure 1) was implemented on a 1.5T Philips Achieva system (Philips Healthcare, Best, The Netherlands). Prior to data acquisition automatic shimming of the volume-of-interest during breath hold was performed. The 3D EPSI sequence had the following parameters: echo time: 10 ms, FOV: 300x100x120mm^3, spatial resolution: 3x3mm^2, number of encoded slices: 12, slice thickness: 10 mm, spectral bandwidth: 1064Hz, spectral resolution: 4.2Hz. The repetition time was 1 second on average depending on heart rate. Data acquisitions were ECG triggered to end systole. To avoid signal folding from outside the FOV due to pulse imperfections, a field of excitation (FOX) of 70-85mm and 80mm for the k_y and k_z phase encoding directions was chosen. In addition, four rest slabs were placed orthogonal to the two phase encoding directions (Figure 2). An Ernst angle excitation of 180°-α_{Ernst}≈120° and a 180° refocusing pulse was used to optimize the SNR_t for the creatine resonance at 3.01ppm. Water-suppressed EPSI data were acquired in healthy volunteers during free breathing in an average scan time of 17min depending on heart rate and respiratory navigator efficiency. Weighted gating was used to minimize respiratory motion with a gating window of 3mm for the central 30% of k-space and with a 5mm gating window for the outer region of k-space. A frequency selective excitation pulse placed on the water resonance was used for water suppression prior to signal excitation. For analysis, 8 slices within the FOX were considered (Figure 3). Spectra from volumes-of-interest were averaged after individual phase correction to ensure phase coherent signal addition.

Results

For testing purposes, 3D EPSI without water suppression was acquired and the signal across the water resonance integrated (Figure 3). The water line width varied from 4 to 35Hz indicating sufficient shim and motion suppression quality. Field map values across the different slices of the heart varied between -50Hz to 50Hz after shimming. Spectra at an equatorial level (slice 4) and from the apical region (slice 6) are shown in Figure 4. In all measured subjects triglyceride and unsaturated fat resonances were well detected.

Discussion

This work has presented the feasibility of 3D EPSI of the human heart. By exploiting local-look excitation, weighted navigator-gating and 2D phase-encoding with echo-planar readouts volumetric mapping of spatial distributions of triglyceride content of the in-vivo heart during free-breathing has become possible. Relative to 2D EPSI the requirements for volumetric field shimming and water-suppression demand careful preparations including respiratory control. Future work is dedicated to address quantification and to study the reproducibility of 3D EPSI in larger subject cohorts.

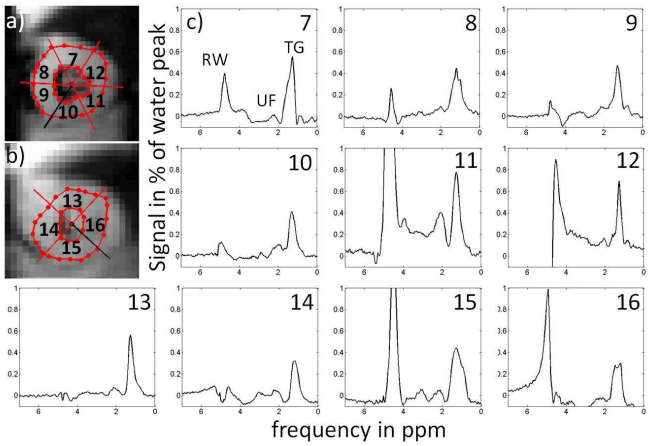

Figure 4: Regions of interest used for data analysis in the equatorial (a) and the apical region (b) of the heart. c) Water suppressed spectra from regions of interest indicated in a) and b). The residual water resonance at 4.7ppm (RW), the unsaturated fat resonance at 2.1ppm (UF) and the triglyceride resonance at 1.3ppm (TG) are marked.

References

[1] Hudsmith et al. JACC Img 2 (2009), [2] Neubauer et al. N Engl J Med 356 (2007), [3] Bottomley et al. Lancet 351 (1998), [4] Szczepaniak et al. Magn. Reson. Med. 49 (2003), [5] Schär et al. Magn. Reson. Med. 51 (2004), [6] v. d. Meer et al. Radiology 245 (2007), [7] Neubauer et al. Heart Fail Rev 12 (2007), [8] Weiss et al. Proc. ISMRM 18 (2010)