THREE DIMENSIONAL MYOCARDIAL T1 MAPPING DURING FREE-BREATHING

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INTRODUCTION: Myocardial T1 mapping is an emerging diagnostic tool for detection of diffuse fibrosis. Conventionally, a two-dimensional (2D) T1 mapping sequence with multiple T1-weighted single-shot images during one breath hold per slice is used (1). However, these single-shot techniques inherently limit the spatial resolution, require numerous breath holds for sufficient coverage, and do not allow for volumetric coverage. In this study, we sought to develop a novel 3D free-breathing T1 mapping sequence to address these limitations.

METHODS: Sequence: The proposed sequence consists of multiple interleaved, segmented inversion recovery SSFP image acquisitions. The effective inversion time is varied among the interleaves to create various T1-weighted contrasts that allow for T1 mapping. A k-space segment of one of the images is acquired per heart cycle with ECG-triggering. Respiratory navigator (NAV) gating is performed with a two-fold scheme, depicted in Figure 1. First, the central k-space is acquired at the beginning of the scan with prospective NAV gating. The nth k-space segment for an interleaved sequence is accepted only if the NAV signal is within the pre-defined gating window for that interleaved sequence moves onto the (n+1)th central k-space segment only if the nth segment has been NAV-accepted for all the interleaves (corresponding to different inversion times). To ensure the longitudinal magnetization recovery trend remains the same throughout the scan, all interleaves for the nth k-space segment are repeated (with a dummy cycle if it has already been NAV-accepted for that interleaved sequence), the same order, until each interleaved segment has been accepted for the nth k-space segment, and the sequence moves onto the (n+1)th segment. Subsequently, the outer k-space is acquired without any prospective respiratory motion compensation, and is retrospectively gated using the NAV signal, where measurements outside the gating-window are discarded. This scheme creates an undersampled outer k-space with a fully sampled k-space center and can be reconstructed using a compressed-sensing algorithm (2). T1 maps are obtained by voxel-wise curve fitting of a two parameter model of the longitudinal magnetization recovery curve to the image intensities.

Phantom Imaging: All imaging was performed on a 1.5T Philips Achieva system. Phantom measurements on a phantom with multiple compartments of different T1s were performed to test the feasibility of the sequence for T1 value estimation without any motion, and to compare the estimated T1 values to those from the Modified Look-Locker (MOLLI) sequence (2).

In-Vivo Imaging: In-vivo 3D T1 mapping was performed in six healthy subjects using the proposed T1 mapping sequence 5-30 minutes after injection of Gd-BOPTA. The 3D T1 mapping sequence was performed during free breathing with a resolution of 1.7×1.7×4mm3 (TR/TE = 3.0/1.28 ms), an acquisition window of 100 ms and a scan time of 5 minutes for 100% gating efficiency at a heart-rate of 60 bpm. For comparison 2D multi slice T1 maps were acquired using MOLLI (in-plane resolution 1.7×2.1 mm2, slice thickness 10mm, SENSE rate 2). Images were quantitatively evaluated in terms of T1 times, and signal homogeneity in the blood and myocardium.

RESULTS: Phantom Imaging: Fig. 2 shows phantom measurements comparing the proposed T1 mapping sequence to 2D MOLLI. It can be seen that the T1 times of the proposed method are underestimating T1 times by up to 12%. The error bars, that represent the variation within each phantom compartment, show that the proposed 3D method provides improved homogeneity compared to 2D T1 mapping.

In-Vivo Imaging: Fig. 3 shows representative T1 maps acquired in a healthy volunteer using the proposed 3D T1 mapping sequence and multi-slice 2D MOLLI. The arrow indicates a MOLLI-slice that suffers from artifacts induced by improper breath holding. No statistical significant difference was found in the T1 times of the myocardium, the left and right ventricles (P > .09). However the 3D T1 maps show an average reduction of the T1 variation in the ventricles by 37%.

The acquisition time using the 3D T1 mapping sequence was between 9 and 15 minutes and between 7 and 10 minutes using MOLLI (including rest periods between breath holds).

CONCLUSIONS: We have proposed a novel sequence for 3D T1 mapping, utilizing multiple interleaved, segmented inversion recovery image acquisitions. A joint prospective-retrospective navigator gating scheme for multiple interleaves enables free-breathing acquisition of 3D T1 maps, which are unsusceptible to motion artifacts induced by improper breath holds. The 3D imaging sequence achieved improved homogeneity, coverage and resolution compared to 2D.