FREE BREATHING 3D LUNG IMAGING USING SELF-GATING WITH AN EFFICIENT SAMPLING SCHEME

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Introduction: Retrospectively gated imaging can remove the requirement for breath holds and enable more time consuming examinations in lung imaging. Quasi-random sampling (QRS) schemes have been shown to be beneficial for this technique [1]. Their incoherent temporal and spatial ordering allows for a uniform spatial distribution over short periods of time compared to linear or pseudo-random sampling. This property is preserved during the gating process. However, retrospective gating may lead to missing lines in k-space which can result in undersampling artifacts. Missing lines close to the k-space center are especially problematic since they produce coherent artifacts. This can partly be overcome by parallel imaging techniques but only if gaps in k-space remain relatively small. For short scan times, this might not be the case. In this work, a sampling scheme is presented that preserves the incoherent temporal order of the uniform QRS while distributing averages according to a normal distribution across k-space. This results in the oversampling of the k-space center, thereby limiting the risk of missing lines near the center. The proposed sampling scheme is compared to sampling with a uniform distribution and shown to offer improved image quality at equal scan times.

Methods: Two sampling patterns for 3D-imaging were compared. The first pattern was created by mapping a sequence of uniformly distributed quasi random numbers [2] to line and partition indices. For the second pattern, the uniformly distributed numbers were transformed to a normal distribution before the mapping. The fast approach to uniformity of quasi random numbers is thus translated into a fast approach to a normal distribution. In the resulting distribution (Fig 1) the central line is sampled about eight times as often as the outermost line. Two data sets using uniform and normal distributions respectively were acquired using a 3D gradient echo sequence with DC-signal collection for each acquired readout [1, 3]. In vivo experiments were performed on healthy volunteers using a six-channel phased-array body matrix in combination with a spine matrix on a clinical 1.5T MR-scanner. Imaging parameters were as follows: TE/TR/α=1.05ms/3.5ms/5°, matrix size=128x128x60, FOV=450x450x210mm³, voxel size=3.5x3.5x3.5mm³, averages=2, acquisition time=54s. Since the sampling is non-uniform, one average here corresponds to 128x60 acquisitions. The DC-navigator signal was smoothed and thresholded to identify and reconstruct the expiration state. Thresholding resulted in a 50% acceptance rate for both measurements. Data from this state were sorted and lines acquired multiple times were averaged. Missing lines were reconstructed using iterative GRAPPA [4].

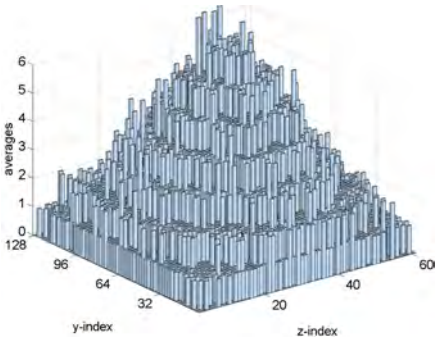

Fig 1.Distribution of averages in k-space for the proposed sampling scheme before gating. Matrix size: 128x60, averages=2

Results: Figure 2 shows the distribution of missing (white) and acquired (black) lines across k-space after gating. Gating resulted in 35.4% missing lines for uniform and 41.8% for normal distributed sampling. Missing lines and clusters of missing lines are evenly distributed across k-space for uniform sampling. The new sampling method with normal distributed sampling exhibits few missing lines in the center, but also has few acquired lines in the outer region of k-space. Figure 3 shows corresponding cutouts from each measurement after GRAPPA reconstruction. Undersampling artifacts (indicated by arrows) are present in images reconstructed from the uniform sampling measurement while being absent for normal distributed sampling. This is despite an overall lesser amount of unique acquired lines. Additional measurements showed that measurements with uniform sampling needed to increase scan time by about 30% in order to achieve the same image quality as measurements with normal distributed sampling (not shown).

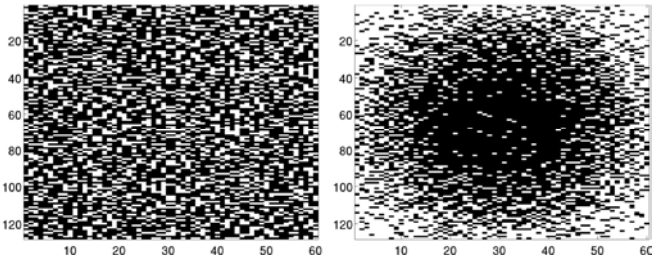

Fig 2. Distribution of missing (white) and acquired (black) lines after gating. Left: uniform, right: normal distributed sampling. Partition indices on horizontal, line indices on vertical axis.

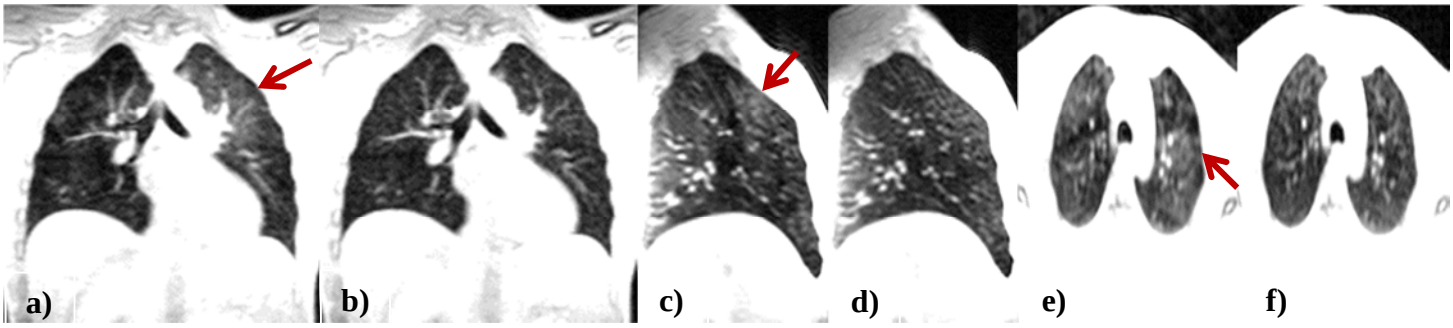

Fig.3 Coronal, sagittal and axial cutouts from reconstructed data sets after application of GRAPPA. Arrows point to undersampling artifacts present in measurements with uniform sampling. a), c), e): uniform random sampling, b), d), f) normal random sampling

Conclusion: Quasi-random sampling enables robust retrospectively gated free breathing measurements. The proposed sampling scheme offers a further reduction in scan time of typically 30%. 3D images with isotropic resolution of 3.5x3.5x3.5mm³ could be obtained in 54s for expiration states.

References: [1] Weick S, et al., Proc ISMRM (2011); [2] Bratley P, et al., ACM Transactions on Modeling and Computer Simulation, 2:3 p 195-213 (1992); [3] Weick S, et al., JMRI (2012), 37:3 p 727-732; [4] Lustig M, et al., MRM 64:2 p 457-471 (2010)

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