Tier-specific weighted echo sharing technique (WEST) for extremely undersampled Cartesian magnetic resonance fingerprinting (MRF)

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Introduction

Magnetic resonance fingerprinting (MRF) is a powerful technique for fast magnetic resonance (MR) parameter (M0, T1, T2, ΔB) mapping [1]. But the variable density spiral (VDS) trajectory used in the MRF is not widely used for clinical systems because its implementation is not robust depending on the stability of MR systems. For the robustness of the MRF in the clinical systems, well-established Cartesian trajectory needs to be considered. In the Cartesian MRF, however, severe aliasing or blurring artifacts on images appear because extreme undersampling should be applied for fast data acquisition. To reduce these artifacts, therefore, the effective data sharing method had been developed to fill the empty phase encoding (PE) lines (k_y lines) through all over the time points. [2] This technique fills the empty PE lines with a weighted combination of acquired PE lines in the same k-space position at other time points. We call this technique as 'weighted echo sharing technique (WEST)' hereafter. This WEST method showed successful results making it possible to undersample the Cartesian k-space data up to the reduction factor R=32. However, the maps obtained using WEST tend to contain high noise that may degrade the resolution and the contrast between different tissues. In this study, we focused on resolving the noise-like artifacts in the MR parameter maps obtained by the WEST method. The results show that the introduction of tier-specific weights to the WEST resulted in substantial reduction of the noise-like artifacts in the estimated parameter maps.

Methods

For *in vivo* experiments, one slice of brain was scanned with inversion-recovery balanced steady state free-precession sequence in 3T MRI system. Used flip angle (FA) and repetition time (TR) patterns were similar to [1]. Number of time points was 500, and the ranges of FAs and TRs were 0~80° and 8~12ms, respectively. Slice thickness was 5mm and matrix size was 256×256. Total two scans were performed for fullsampling case (256 PE lines) and undersampling case (8 PE lines, R=32). All image reconstruction and processing were performed using MATLAB (The MathWorks, Inc., Natick, MA).

In Fig. 1, the basic idea of the WEST method is introduced. In the WEST, empty PE line is filled with a weighted combination of several PE lines in the same k-space position at other time points. To obtain the weights, center PE lines are acquired for all time points during data acquisition. The weights to fill the y_i-th empty PE lines at the t_j*-th* time point are obtained by representing the center PE line at the t_j*-th* time point by weighted combination of center PE lines at the time points which contain acquired y_i*-th* PE line. And the empty PE line is filled with weighted combination of y_i*-th* acquired PE lines by using obtained weights. However, this WEST method introduces some amount of error in the overall k-space because the obtained weights from the center PE line are not optimal weights to fill empty PE lines. And the overall error in the k-space is expressed as noise-like artifacts in the image domain. To reduce the noise like artifacts on images (i.e. error in overall k-space), the weights used in the WEST have to be obtained for each region of k-space. And the illustration of the tier-specific WEST is shown in Fig 2. First, a k-space is separated to two tiers with center (low frequency) tier and outer (high frequency) tier. Also, the center PE line is separated to two parts with center parts and outer parts (red lines of each tier) to obtain tier-specific weights. And the weights for two different tiers are obtained by using the two different parts of the center PE line. Finally the WEST was performed for two different tiers by using their specific weights.

Results

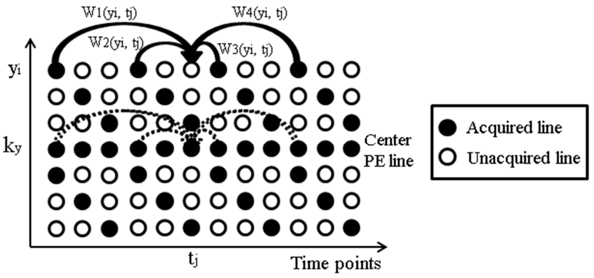

Fig 1. Basic idea of the WEST method is introduced. Acquisition of weights is indicated as dash curves. And the empty y_i-th PE line at the t_j-th time point is filled with weighted combination of acquired y_i-th PE lines at other time points. This is indicated as full curves.

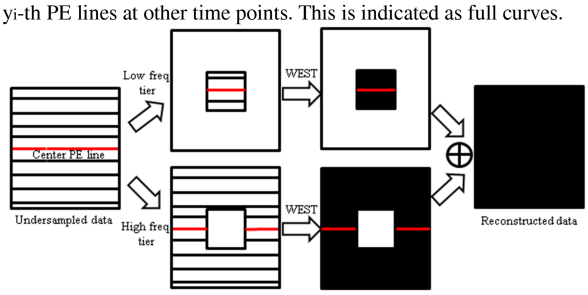

Fig 2. Basic idea of the tier-specific WEST method is introduced. A k-space is separated to center (low frequency) and outer (high frequency) tiers. And the WEST is performed for two different tiers by using two different parts (center and outer) of center PE lines.

	Full sampled		WEST (R=32)		Tier-specific WEST (R=32)	
ROI std (ms)	T1	T2	T1	T2	T1	T2
	38.1	2.8	65.9	7.1	51.3	4.0

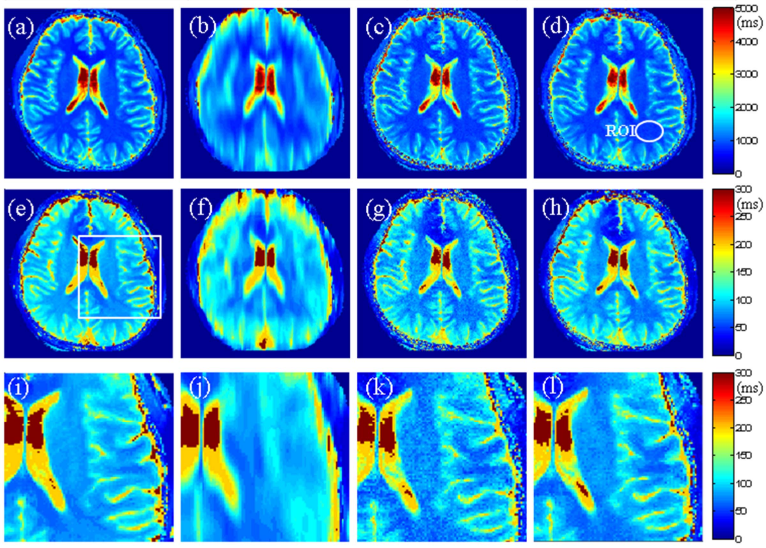

Fig 3. Estimated T1 maps from fullsampled data (a), random undersampled data (R=32) (b), the conventional WEST (R=32) (c), and the tier-specific WEST (R=32) (d) are shown. T2 maps are also shown with same order at (e-h). Enlarged of T2 maps are shown at (i-l). The above table shows standard deviations in indicated ROI in (d).

Fig 3 shows the estimated T1, T2, and enlarged T2 maps from fullsampled data (a,e,i), random undersampled data (b,f,j), the conventional WEST (c,g,k), and the tier-specific WEST (d,h,l). The aliasing and blurring artifacts due to random undersampling in the maps were highly reduced in the conventional WEST case compared to the random undersampled case (non-sharing). Also, the maps show more detailed and accurate structures of the brain. However, still some of detail tissues and structures in each map are hard to be distinguished due to the noise-like artifacts. Finally, the maps obtained by the tier-specific WEST show substantially reduced noise-like artifacts compared to the conventional WEST. And they are very similar with maps estimated from fullsampled data. The standard deviations in selected homogeneous ROI in fig 3-(d) show the noise level in maps was sufficiently reduced in the tier-specific WEST case.

Conclusion

Proposed tier-specific WEST method could sufficiently suppress the noise-like artifacts in the maps obtained by the conventional WEST. Consequently, this method enables acquisition of accurate maps from extremely undersampled Cartesian MRF data.

Acknowledgement This work was supported by Samsung Electronics.

Reference [1] Dan Ma et al., "*Magnetic resonance fingerprinting*", *NATURE*, vol 495, 2013
[2] Taejoon Eo et. al., "*Effective data sharing method for extreme Cartesian undersampling in MRF",* ISMRM, 2014