MP-RAGE with Square-Spiral Phase Encoding Order: SNR & CNR Enhancement in Reduced Scan Times

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Introduction

Magnetization prepared, rapid gradient echo (MP-RAGE) is a 3D sequence which allows the acquisition of T_1 weighted volumes with good tissue contrast in reasonable scan times [1]. It is widely used in clinical routine especially in brain imaging with a focus on the gray matter / white matter contrast-to-noise-ratio (WM/GM CNR). MP-RAGE is an inversion recovery sequence with two phase encode (PE) dimensions, one of those is completely acquired after the inversion pulse within an inner loop of gradient echoes. Here, the importance of PE order of the inner loop is well-known [2]. A centric ordering scheme improves SNR and CNR but the resolution, however, is sacrificed due to blurring of the point spread function (PSF) along the centrically ordered coordinate [2,3]. This might be compensated by flip-angle variation, which unfortunately reduces the SNR/CNR ratio again [3]. Here, we present an interleaved square spiral phase encoding order scheme taking advantage of the 3D nature of the sequence, which is the natural 3D extension of the 2D-centric ordering [4]. The scheme offers great flexibility for SNR/CNR enhancement, PSF tightening, and acquisition time reduction, as well as a very good compromise between these conflicting attributes.

Methods

In order to facilitate a deeper understanding of the MP-RAGE sequence, we performed simulations based on configuration theory for SSFP sequences [5]. Fig. 1a) depicts the decay of transversal magnetization along a train of low flip angle RF pulses (flip angle=15°, TR=10ms, RF spoiled) for brain tissue, WM (T1/T2=600/70ms, M_0=0.9) and GM (T1/T2=900/85ms, M_0=1), as well as the WM-GM signal difference. The initial longitudinal magnetization was manipulated by inversion recovery with an inversion time TI=730ms, which yields maximal WM-GM signal difference. The basic idea of the spiral is to perform the phase encoding steps along a square spiral in the (k_y , k_z) plane in k-space. Magnetization preparation is performed M times, each followed by a train of N low flip angle RF pulses. Thus $MN=N_y N_z$, where (N_y , N_z) is the matrix size in PE dimensions. The N phase encoding steps following each inversion pulses are performed in an interleaved manner along the spiral [4]. The M readouts which have the maximum SNR/CNR – i.e. the readout of the first pulse after MP – fill the inner M points on the spiral, then the next M points on the spiral are given by the M readouts coming from the second pulse after each MP, etc (cf. Fig. 1b, where different symbols denote readouts from different MP steps). Now, a 2D-PSF has to be considered in the x-y plane, which we obtained from simulating the spiral acquisition (Fig. 1c,d). PSF shaping can be performed by variation of the parameters N and M. Variable flip angles, however, will be considered at a later stage. The acquisition time, TA, is equal to that of standard MP-RAGE, if $M=N_y$. Using less MP steps, the acquisition time can be reduced by $(N_y-M)\times(TI+TD)$. Furthermore, the length of the pulse train $N=(N_y N_z)/M$ can also be reduced (in order to increase SNR/CNR and/or to shape the PSF) for the N acquired readouts per MP step. For this case, $(N_y N_z)/M-N$ points are missing on the outer part of the spiral. Since these regions do not significantly contribute to SNR/CNR, we acquire them without MP. This is performed after the last inversion pulse, where the RF train of N pulses is simply extended until the whole k-space is acquired, which results in a steady-state acquisition of the outer part of k-space. For WM/GM contrast brain imaging, the proposed approach would need additional pre-saturation pulses for CSF suppression. Instead, the steady-state acquisition of the outer parts of k-space (i.e. $MN<N_y N_z$) can be performed in the beginning to suppress signal from tissue with long T_1.

Results

Fig. 2 depicts phantom measurements for the comparison of MP-RAGE with different PE ordering: a) linear, b) centric, c) spiral MP-RAGE with 40% reduced TA, respectively. Containers **1** and **2** have T_1 similar to WM and GM, respectively. The three compared sequences were each optimized for CNR. Results [a),b),c)] normalized to the linear approach for SNR_1, SNR_2, and CNR_{1-2}, are [1, 1.2, 1.4], [1, 0.8, 0.9], and [1, 1.9, 2.1] , respectively, clearly showing the advantage of the our approach. Fig. 2 d), e), and f) show *in vivo* results comparing linear, centric, and spiral PE, respectively, the latter again with 40% reduced scan time. All measurements were performed on a 1.5 Tesla Siemens Sonata MR scanner.

Conclusion and Discussion

The implemented MP-RAGE sequence introduces an interleaved data reordering along a square-spiral in the 2D phase-encoded k-space in order to achieve the maximum possible SNR/CNR with such a T_1-weighted sequence. The compact acquisition of SNR/CNR in the center of the spiral allows significant scan time reduction by omitting MP steps in outer parts of k-space. These initial results have been obtain without sequence parameter optimization. Nevertheless, the approach shows the predicted improvement. PSF shaping has been investigated by simulations. This research has to be extended to find the sequence parameters giving optimal resolution.

References

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Figure 1

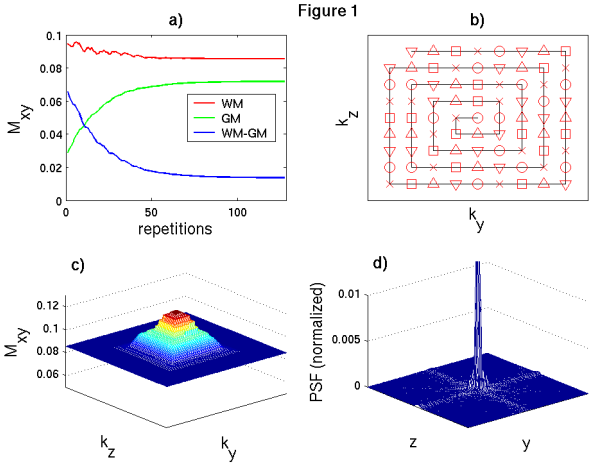

Figure 2