Optimization of 3D MP-RAGE sequences for structural brain imaging

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Introduction: 3D MP-RAGE is a well known sequence for T1-weighted three-dimensional imaging [1]: after an inversion pulse and a delay TI a series of gradient echoes with different 3D phase encoding is acquired, followed by a relaxation delay TD. This is repeated for different values of the 2D phase encoding gradient. A major drawback of this method is the loss of T1 contrast during the acquisition process, especially if a large number of 3D partitions is required. A solution is to use centric phase encoding which, however, leads to poor contrast within small tissue structures [2,3]. The use of variable flip angles has been suggested [4]. However, this may be difficult to implement on standard MRI scanners. This work describes an optimization of 3D MP-RAGE sequences based on centric phase encoded spoiled FLASH imaging [5] for structural brain mapping.

Theory: The achievable white matter/gray matter signal difference (WGSD) was calculated by assuming a T1 relaxation during TI and TD, a T1* relaxation during the acquisition [6] and evaluating the steady state within the 2D loop. The longitudinal magnetization of white and gray matter during the acquisition process is given by $M_w(t)$ and $M_g(t)$, respectively. There is maximum contrast at $t=0$ when the central k-space lines are acquired. However, the contrast decreases for $t>0$, leading to poor image contrasts if a small region of one tissue type is embedded in a large region of other tissue. This problem may be overcome by appropriate filtering of the raw data: the n-th echo in the echo train is multiplied by $F_n = [1 - (1 - a)b^{n-1}]^{-1}$ where $a$ and $b$ are chosen appropriately. A second problem is the inhomogeneity of the RF head coil in longitudinal (z-)direction leading to pronounced signal losses in the upper and lower parts of the brain. This problem may be overcome by using compensation pulses for excitation which display a parabolic profile and are applied while a z-gradient is switched on.

Method: Brain images of 4 healthy volunteers with an isotropic resolution of 1mm were acquired with different MP-RAGE sequences. For all sequences, the parameters were: TR/TE/\alpha=10.5ms/4ms/12°, matrix=256x224, FOV=256mm x 224mm, 176 partitions, effective slice thickness=1mm. TI/TD were optimized for the respective phase encoding types using the simulation procedure explained above and amounted to 600ms/900ms (linear) and 1000ms/500ms (centric). Scanning time was 12:32 min for all sequences. In the case of centric phase encoding, a postprocessing filter with $a=0.6$, $b=0.965$ and a compensation pulse for excitation were used. For comparison, 2 additional centric phase encoded sequences were run, one without filtering and one without using the compensation pulse. The sequences were compared by evaluating the signal to noise ratio (SNR) in white and gray matter and the WGSD/Noise ratio. In all cases, gray matter images were obtained by using a segmentation algorithm [7].

Results: The use of centric phase encoding resulted in a 10-20% increase in SNR for white matter and an unchanged SNR for gray matter. The WGSD/Noise ratio improved by up to 100%. The quality of the segmented gray matter map was considerably higher for the data acquired with centric phase encoding (Fig. 1). The results from the 2 additional sequences showed clearly the importance of the compensation procedures described above: images acquired without filtering were blurred and after gray matter segmentation small structures displayed low resolution. Images acquired with a non-selective excitation pulse instead of the compensation pulse displayed pronounced signal losses in the upper part of the brain and caused segmentation to fail (Fig. 2). However, these effects could be compensated for completely in the centric phase encoded MP-RAGE sequence using the postprocessing filter and the compensation pulse.

References: