Reduced FOV Excitation Using Spatial-Spectral RF Pulses and Second-Order Gradients: Experimental Verification

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INTRODUCTION: Multidimensional, spatially selective RF pulses have wide applications in MR imaging/spectroscopy experiments. A key limitation of multidimensional RF pulses is their long duration needed to traverse the multidimensional excitation k-space. Conventional efforts to address this problem include the use of multiple RF transmit coils for parallel excitation [1-2]. Recently, high-order, non-linear gradients are exploited to reduce multidimensional RF pulse length [3-6]. We have recently proposed a new method for reduced FOV excitation using spatial-spectral RF pulses and second-order gradients [7]. The method leverages the unique spatial dependence of the second-order gradients to excite a circular region-of-interest (ROI) in a thin slice using a 2D spatial-spectral RF pulse. Based on the design method presented in [7], this work presents the first experimental results of the method on a 3.0T commercial MRI scanner.

METHOD: The goal is to excite a circular ROI of radius R, thickness d and flip angle θ (*i.e.* $|M_{xy}(x,y,z)|=M_0 \sin\theta$, if $x^2+y^2 \le R^2, |z| \le d/2$; 0, otherwise). A static second-order gradient in the form of $z^2-(x^2+y^2)/2$ (Z2 gradient) is applied during excitation. Such a Z2 gradient establishes a unique relationship between resonance frequency and spatial location, which is especially suitable for circular ROI excitation. Notably, in the target slice ($|z| \le d/2$), the resonance frequency is approximately a function of the distance to the origin: f=$-(\gamma/4\pi)G_{Z2}r^2$, r=$(x^2+y^2)^{1/2}$. With the Z2 gradient, a spatial-spectral RF pulse is used to achieve the target excitation pattern. Especially, the slice-selectivity of the pulse avoids undesired excitation outside the target slice, and the frequency-selectivity of the pulse achieves spatial selectivity in the radial direction within the target slice. Therefore, with the Z2 gradient, a 2D spatial-spectral pulse can achieve 3D spatial selectivity! Suppose the main-lobe width of the spatial-spectral RF pulse is BW, and the first excitation replicate is at $\pm f_{rep}$ along the frequency axis. Then, the radius of the excited ROI is $[BW/(\gamma G_{Z2}/2\pi)]^{1/2}$, and the first excitation side-lobe is at r=$[f_{rep}/(\gamma G_{Z2}/4\pi)]^{1/2}$. Based on the above relationships, the target circular ROI can be excited by properly choosing BW and f_{rep} of the spatial-spectral pulse and the Z2 gradient strength G_{Z2} (more details of the design procedure of the proposed method can be found in [7]).

The experiments were performed on a 3.0T GE scanner. The Z2 gradient strength was controlled by changing the shimming current value. To calibrate the Z2 gradient strength, B_0 mapping was performed using a multi-slice GRE sequence. For a given shimming current value, the measured B_0 map was fitted using gradients up to the second-order in a minimum least-square fashion. The experiments were carried out using an EPI sequence with a sphere water phantom of radius 16 cm. The main-lobe bandwith of the 9 ms spatial-spectral pulse of the sequence was 400 Hz, the first excitation replicate was at ± 800 Hz, and the slice thickness was 8 mm. The Z2 gradient strength was 704.5 uT/m^2 (the maximum available Z2 gradient of the scanner was about 2000 uT/m^2). The radius of the resulting excitation pattern was 11.5 cm. The position of the first excitation side-lobe was at r=23.1 cm. The imaging matrix was 64×64. An image domain post-processing method [8] was used to correct the distortions of the reconstructed images caused by the static Z2 gradient during data acquisition.

RESULTS: Figure 1a and 1b show the full FOV (40 cm) imaging results without and with reduced FOV excitation, respectively. Figure 1c and 1d show the imaging results with 0.65 FOV in the phase-encoding direction without and with reduced FOV excitation, respectively. The above results clearly demonstrate that with the Z2 gradient field readily available on a commercial MRI scanner successful reduced FOV excitation can be achieved using the presented method. The residual geometric distortions in Fig. 1b and 1d are likely due to the background B_0 inhomogeneity, since similar distortions can also be found in Fig. 1a, where the Z2 gradient current was 0.

CONCLUSION: We have experimentally demonstrated that reduced FOV excitation can be efficiently accomplished using spatial-spectral RF pulses and second-order gradients. As compared with traditional RF excitation in the presence of linear gradients, the new method requires much shorter RF pulses.

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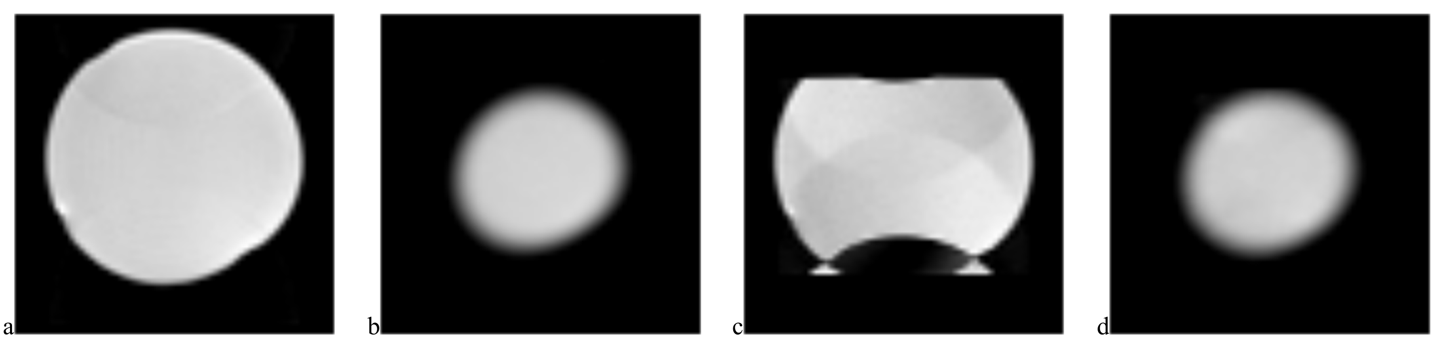

Figure 1. **(a)**: full FOV, without reduced FOV excitation. **(b)**: full FOV, with reduced FOV excitation. **(c)**: 0.65 FOV in phase encoding direction, without reduced FOV excitation. **(d)**: 0.65 FOV in phase encoding direction, with reduced FOV excitation.