SERA: A technique to improve the performance of the 3D sequence by reducing aliasing artifacts in edge slices

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Introduction: It has been shown that the 3D acquisition method can provide better temporal Signal to Noise Ratio (tSNR) for high-resolution fMRI studies (1) compared to the 2D acquisition method. However, there are several practical issues that lower the efficiency of the 3D method and make it less attractive than the 2D method. Among them, an important one is the wrap-around aliasing artifact in the slice-select direction. For 3D acquisition, the thickness of the excited slab is usually set equal to the field of view in the slice-select direction (zFOV) to maintain acquisition efficiency. If zFOV is big enough to cover the whole brain, there is no need to worry about aliasing artifacts. However, using a very large zFOV is not practical in high-resolution fMRI because it requires a large amount of phase encodings in slice-select direction, which cannot be easily fit into an acceptable volume TR. When zFOV is smaller than the brain, aliasing artifacts show up in edge slices. Using a high performance excitation pulse with a sharp transition band can significantly reduce the number of slices affected by aliasing artifacts. However, the highest time-bandwidth product is limited by the maximal B_1 that a RF system can provide. Typically, with the use of the high performance excitation pulse, only one slice at each end is severely contaminated by aliasing artifacts. Although throwing away those two slices can easily solve the problem, it surely reduces the efficiency of the 3D method, especially when the number of slices is not large. In this work, a new technique called Slab Excitation with Reduced Aliasing (SERA) is introduced. The SERA technique can be illustrated in Figure 1. It excites and saturates spins in two thin slices (one at each edge) that are just beyond zFOV before the traditional high performance excitation pulse excites the whole slab for 3D acquisition. Since spins outside of zFOV that might be excited by the high performance excitation pulse are saturated at the beginning, they won't contribute to the signal. Therefore, aliasing artifacts in edge slices can be greatly reduced.

Figure 1. Illustration of the SERA technique. It excites and saturates two thin slices at the edges (black) before excitation of a big slab (red) for 3D acquisition.

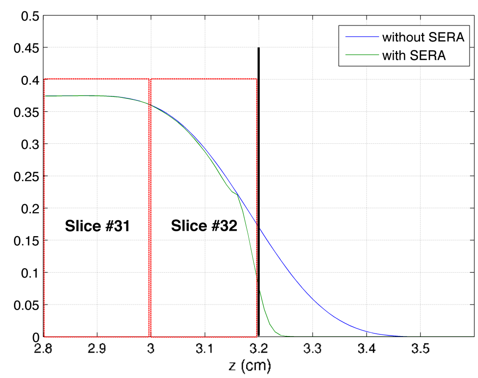

Figure 2. Simulated slab profiles with (green) and without (blue) the SERA technique. Black vertical bar indicates the edge of zFOV. Equivalent slices are shown in red rectangles.

Methods: The high performance excitation pulse used in our 3D stack-of-spirals sequence (2) was specially designed to have a sharp transition. Design parameters are listed here. Pulse duration is 6.4ms, resolution is 1600, time bandwidth product is 46, maximal achievable flip angle is 30°, passband ripple is 0.001 and stopband ripple is 0.0001. Based on simulation results, the transition bandwidth of this excitation pulse roughly equals to 1/23 of the excited bandwidth. Images collected with this sequence were used as a reference and compared to those acquired with the SERA technique to verify its effectiveness. The implementation of the SERA technique was done based on our current 3D stack-of-spirals sequence. Two identical 90° RF pulses, with their center frequencies adjusted to excited two thin slices (one at each edge) immediately adjacent to zFOV, and one gradient crusher were inserted before the excitation pulse. Simple windowed SINC pulse was used to test the idea. Each pulse has a duration of 3.2ms, a resolution of 800, a time bandwidth product of 8 and a bandwidth equal to the transition bandwidth of the excitation pulse. The gradient crusher has an area of 4 G/cm•ms. To compare 3D sequences with and without the SERA technique, simulation was performed in MATLAB. In addition, MRI scans were performed on a GEL phantom using typical imaging parameters for fMRI studies (TE=30ms, TR=3s, FA=22°, xFOV=yFOV=22cm, zFOV=64mm, Encoding matrix=96*96*32).

Results: Simulation results are shown in Figure 2. Only the right edge of excited slab profiles are shown here because 1) the profile of excited slice is symmetric and 2) that is where the difference stays. The edge of zFOV is marked by a black vertical bar and the locations of equivalent slices are shown in red boxes. It can be seen that without the SERA technique, there is a significant amount of magnetization outside of zFOV, which will alias to the other end, whereas the magnetization outside of zFOV is greatly suppressed with the use of the SERA technique. The edge slices (one from each end) acquired by the 3D sequence with and without the SERA technique are shown in Figure 3a, 3b, 3c and 3d respectively. Aliasing artifacts are significant in the traditional 3D sequence (3c and 3d), but become unnoticeable by using the SERA technique (3a and 3b), which proves the effectiveness of the proposed technique.

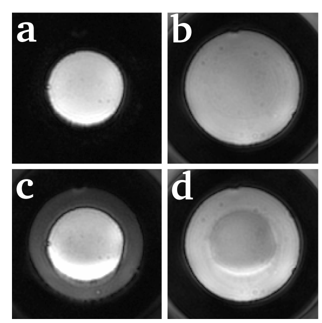

Figure 3. The edge slices (slice 1 and 32) with and without the SERA technique are shown in a, b, c and d respectively. To compare directly, a and c share the same display scale. So does b and d.

Discussion: In this work, we have shown that the SERA technique can be used to suppress the signal outside of zFOV and reduce aliasing artifacts in edge slices in cases where the object is larger than zFOV. The efficiency of 3D acquisition can be improved by using this technique since all edge slices are preserved. The thickness of slices excited and saturated by the SERA technique is in general very small because we only need to suppress a bandwidth which is equal to the transition bandwidth of the high performance excitation pulse. Therefore the edges of the two saturated slices are significantly sharper than those of the excited slab. Since the SERA technique only takes the transition bandwidth of the excitation pulse as an input, it can basically work with any excitation pulses used in existing 3D sequences. There is one thing we should pay attention. When the thickness of saturated slices is too small, it may require a gradient strength that is beyond the capability of the hardware. Should that happen, we would have to combine the two RF pulses, or increase the slice thickness, or increase the pulse duration to lower the requirement to the gradient system.

References:
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