Segmented 2D-Selective RF Excitations with Weighted Averaging and Flip Angle Adaptation for MR Spectroscopy of Irregularly Shaped Voxel

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Introduction

2D-selective RF (2DRF) excitations [1,2] are able to define 2D profiles of arbitrary shape which, e.g, can be used to minimize partial volume effects in single-voxel MRS [3,4]. In this study, a weighted averaging scheme with flip angle adaptation is presented for segmented 2DRF excitations and applied to single-line segments of a blipped-planar trajectory. Segments covering the central k-space, i.e. those with significant signal contributions, are averaged more often than the (outer) segments with low RF amplitudes and minor signal contributions. For compensation, these outer segments are applied with an increased RF amplitude, i.e. a larger flip angle, such that an unaltered signal contribution is obtained in a reduced number of shots. Numerical simulations and experiments in phantoms and the human brain in vivo demonstrate that the approach considerably increases the signal efficiency, i.e. the signal accumulated per time unit, without introducing profile distortions. Its application to single-voxel MR spectroscopy of a corpus-callosum-shaped region-of-interest yielded, due to an optimum coverage of the target volume, higher signal amplitudes than conventional localization based on cross-sectional RF excitations. Thus, the approach could improve the reliability of single-voxel MR spectroscopy.

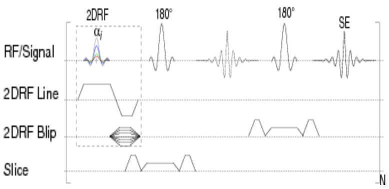

Fig. 1: Pulse sequence for a PRESS-based single-voxel acquisition with single-line segments of a blipped-planar 2DRF excitation. The first refocusing RF pulse defines the voxel size in the slice direction, the second one eliminates the unwanted side excitations appearing in the blip direction.

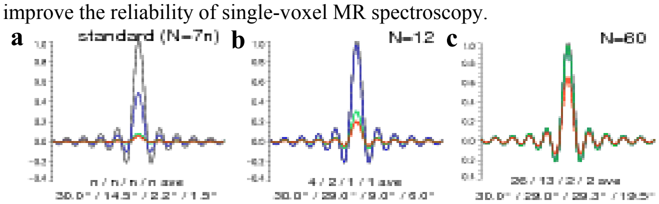

Fig. 2: Segments #4–#7 of a 7-line 2DRF excitation with (a) standard and weighted averaging with (b) 12 and (c) 60 acquisitions.

Theory

Figure 1 shows a basic pulse sequence for single-voxel MRS using a segmented 2DRF excitation to define an arbitrary 2D profile. Note that complex averaging of all signals acquired with the different segments is required to obtain the desired excitation profile. To the *i*th 2DRF segment, a flip angle α_i can be assigned which, in general, will differ between the segments, e.g., being larger for segments covering central *k*-space lines but lower for outer segments (see Fig. 2). If averaging is required as in single-voxel MRS, all segments usually have the same number of averages *n* which yields a signal amplitude of $n \cdot \sin \alpha_i$. However, rather than performing multiple averages with a low flip angle and minor signal amplitudes for outer segments, it is more efficient to reduce the number of averages for these segments and increase the flip angle accordingly (see Fig. 2) such that the same signal amplitude is accumulated in a reduced number of shots, i.e. $n_i' \cdot \sin \alpha_i' = n \cdot \sin \alpha_i$ or in the low-flip-angle approximation ($\sin \alpha \approx \alpha$) $n_i' \alpha_i' = n\alpha_i$ where n_i' and α_i' are the reduced number of averages and the adapted flip angle, respectively. For large *N*, the adapted flip angles α_i' converge and their different initial values (α_i) are reflected in the different number of averages n_i' of the segments.

Methods

2DRF excitations (flip angle 30°) were designed under the low-flip-angle approximation [2] with a resolution of 5×5 mm^2 and a field-of-excitation of 35 mm (7 *k*-space lines). A rectangular and a corpus-callosum-shaped excitation profile defined on a T1-weighted image of a healthy volunteer were investigated. Numerical simulations as well as phantom measurements of the excitation profile and single-voxel MRS were performed to assess the signal efficiency of standard and weighted averaging compared to an unsegmented 2DRF excitation. MR spectra were acquired for a TE of 30 ms with a TR of 6s and 60–63 acquisitions and were analyzed using LCModel.

Results and Discussion

No significant profile distortions were observed for the weighted averaging approach as can be seen in Fig. 3 for the rectangular excitation profile. Figure 4 presents the signal efficiency per shot (relative to an unsegmented 2DRF) and shows the about three-fold improvement observed for weighted averaging achieved already for about 20 acquisitions. Profile acquisitions and MR spectra of the irregularly shaped corpus-callosum target volume acquired in a phantom are shown in Fig. 5 and show that the efficiency increase is comparable.

In vivo spectra of a healthy volunteer are presented in Fig. 6. Compared to conventional localization based on cross-sectional RF excitations, segmented 2DRF excitations with weighted averaging cover the full target volume without introducing partial volume effects and yield an increased signal amplitude.

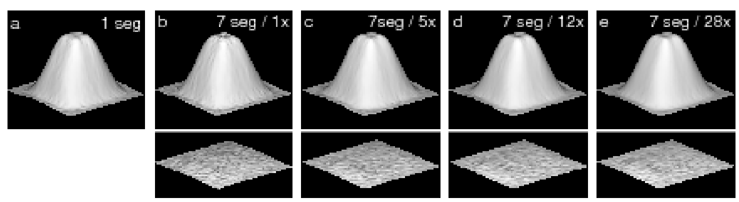

Fig. 3: Measured excitation profiles obtained with (a) unsegmented and (b–e) segmented 2DRF excitations using (b) standard and (c–e) weighted averaging. The lower plots represent the difference compared to (a).

For large flip angles (90°), slight profile distortions occur which degrade the localization for single-voxel MRS (data not shown). Thus, an RF pulse design beyond the low-flip-angle approximation seems to be required in this regime, however, the basic principles of the weighted averaging approach are expected to remain valid.

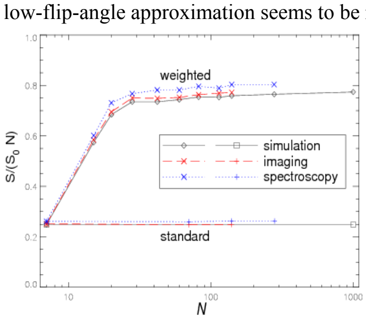

Fig. 4: Signal accumulated per shot vs. the total number of acquisition *N* for a rectangular excitation profile

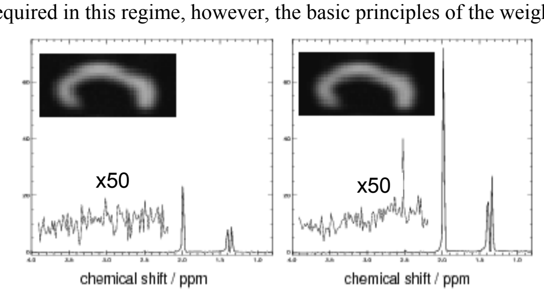

Fig. 5: Profile acquisitions and MR spectra obtained in a MRS phantom for the corpus-callosum-shaped profile with standard (left, 63 acquisitions) and weighted averaging (right, 60 acquisitions).

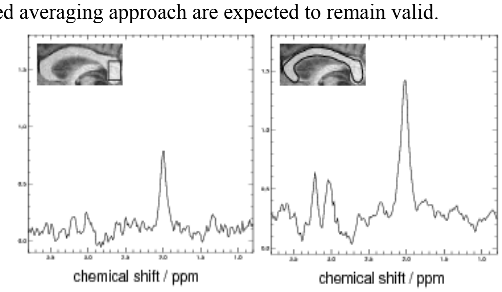

Fig. 6: In vivo MR spectra (63 acquisitions) of the corpus callosum with a conventional cuboidal voxel defined by cross-sectional RF excitations (90°, left) and an irregularly shaped voxel using segmented 2DRF excitations with weighted averaging (30°, right).

References

[1] Bottomley PA, Hardy CJ, J. Appl. Phys. **62**, 4284–4290 (1987)
[2] Pauly J *et al*., J. Magn. Reson. **81**, 43–56 (1989)
[3] Qin Q *et al.*, Magn. Reson. Med. **58**, 19–26 (2007)
[4] Weber-Fahr W *et al.*, Magn. Reson. Imaging **27**, 664–671 (2009)