Quantification of k-Space Filtering to Compare SNR and Improve Parallel MRI Acquisitions with Hyperpolarized Nuclei

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Introduction:

MRI using hyperpolarized 3-Helium (HP-^{3}HE) is an effective tool to obtain morphological or functional information not achievable with proton MRI. The signal to noise ration (SNR) and k-space filtering are the two principal features which characterize image quality. The decay of magnetization during the MRI acquisition causes weighting of the k-space data points and therefore k-space filtering [1].

The equation $\alpha = atan\left(\sqrt{2/N}\right)$ is commonly used to calculate the optimal flip angle (FA) for acquisition with constant FA [3]. This equation provides optimal SNR for sequential phase encoding (PE) ordering but it does not take k-space filtering into consideration. Nevertheless, this method provides fair image quality for conventional HP-^{3}HE MRI (multislice acquisition). However, the limitation of this equation is that it cannot be applied when doing SNR comparison between different sampling strategies as images with different k-space filtering would be compared. That is the case when comparing different parallel Imaging (PI) acceleration or slice ordering strategies.

In order to investigate this problem and to find a method for a SNR comparison between sampling trajectories, simulations of the k-space filtering for different acquisition strategies were performed.

Methods:

The power of the k-space filter can be measured via width of the point spread function (PSF). In earlier studies, the method for characterizing the PSF for accelerated acquisition with PI, [2] and, therefore, for quantitatively measuring the k-space filter power (P_{ksf}) via the ratio between first neighbour pixel value and center pixel value of the PSF: P_{ksf} = |PSF(1)| / |PSF(0)| has been established. This parameter characterizes the signal "contamination" from one pixel on direct neighbouring pixels.

First, simulations of P_{ksf} for the standard optimal FA calculation method as applied to the multi-slice and 3D acquisition were performed. Second, the simulated SNR for different PI acceleration factors and sampling strategies which provide the same k-space filtering were calculated. These simulation were performed using the value of relaxation time of hyperpolarized 3He in lung, T1=15s and TR=10ms.

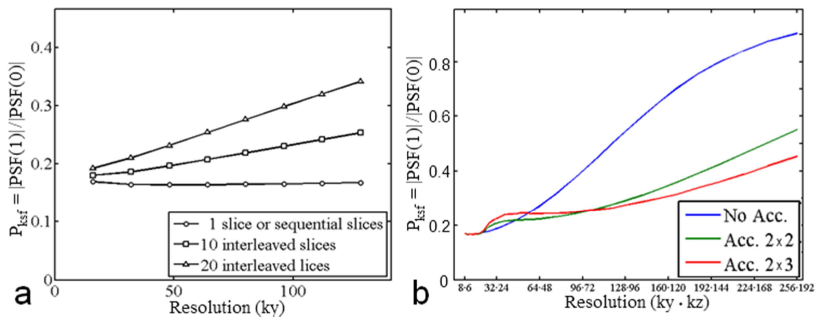

Fig.1. Simulated k-space filtering quantification (P_{ksf}) vs resolution for 2D (a) and 3D (b) acquisition performed with different slice ordering strategies and acceleration

	PE	FA (°)	P_{ksf}	SNR (a.u.) 1st Slice	SNR (a.u.) 10th Slice
No Acc.	Seq.	7.18*	0.168	1	0.562
	Centric	6.20**	0.165	1.464	0.823
Acc. 2	Seq.	9.59*	0.151	0.959	0.694
	Centric	8.75**	0.165	1.458	1.055
Acc. 3	Seq.	10.61*	0.130	0.869	0.667
	Centric	10.05**	0.165	1.366	1.048

Table 1: FA calculated with the standard method (*) or to provide P_{ksf}=0.165 (**)

Results and discussion:

Using sequential slice ordering for 2D acquisition, P_{ksf} was measured to be in the order of 0.17 (Fig.1-a) for commonly used range of matrix size and image resolution. When using interleaved slices the k-space filtering grew leading to a degradation of the image quality. For 3D measurement, only very low matrix size acquisition may also provide the k-space filter power P_{ksf} =0.17. With high resolution matrix (64 x 48 and higher), the P_{ksf} increases dramatically (Fig.1-b). The increase of P_{ksf} results from the longer acquisition time in single slice volume and therefore from a higher impact of T1 relaxation. Reducing the acquisition time, by acquiring less phase encoding with PI reduces the k-space filtering respectively.

Calculation of the flip angles to provide equal k-space filtering for different accelerations (i.e., equal P_{ksf}) allowed estimation of the gain or loss in SNR resulted from the use of parallel imaging acceleration (Tab.1). For an acquisition matrix of 128x128 accelerating the acquisition by factor R=2 leds to a loss of 1% SNR for the first acquired slice (centric phase encoding ordering) but to an increase of 28% SNR for the 10th slice. That assumed that the slices are acquired in a sequential manner.

Conclusion:

So far, the importance of k-space filtering has been underestimated and sometimes ignored, as the images acquired with the standard optimal flip angle choice method usually provides acceptable k-space filter power for 2D slice selective acquisition. However for a long acquisition time in single excited volume (cf. 3D or interleaved 2D), its impact on image quality cannot be ignored. The value P_{ksf} around 0.17 used by the community gives an acceptable image quality. However, the unbiased quantitative criteria of the optimal k-space filtering power still need to be established.

[1]Wild JM et al., MRM 47(4) 687-695. [2] Rivoire J et al. (2010) Proceedings of ISMRM#2575. [3] Mugler JP III et al. (1998) Proceedings of ISMRM #1904.
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