Improve Image Homogeneity of High-Resolution DWI

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Introduction Diffusion Weighted Imaging (DWI) is an important MR technique for detecting subtle lesions, investigating cancer time course, characterizing tissue physiology, neuroradiology, and functional imaging. Despite recent advances, single-shot-EPI is still the most popular form of DWI, due to its robustness and imaging speed. However, it suffers from geometric distortions and T2/T2* induced blurring. Such problems become even exaggerated when high resolution DW images are desired. Readout-segmented EPI has been considered for high resolution DWI [(1)], yet this technique is internally time-consuming and sensitive to phase errors induced by motion during diffusion gradients. An alternative way to achieve high resolution DWI is to reduce the phase encoding FOV (pFOV) using 2D excitation [(2)]. A critical aspect of this technique is the excitation homogeneity, which is however heavily sensitive to the design of the 2D RF and the hardware limitations. This article proposes a 2D excitation technique that employs a pair of walking-saturation, which increases the excitation homogeneity along pFOV without extra hardware requirements.

Theory In 2D excitation technique, the excitation RF consists of a series of sub-pulses, and it is the sub-pulse profile determines the excitation profile in pFOV direction and hence the image homogeneity, as illustrated in Fig 1. Adding more side lobes to the sub-pulses yields better excitation homogeneity. However, to keep the duration of each sub-pulse, more side lobes means a narrower main lobe, which then demands a higher peak B1 to achieve the same flip angle. Besides, narrower main-lobe leads to higher sub-pulse bandwidth, requiring higher gradient amplitude to obtain the same excitation FOV. Since max B1 and max gradient amplitude / slew-rate are all limited by the hardware, the 2D excitation profile is usually sub-optimal on the commercial scanners.

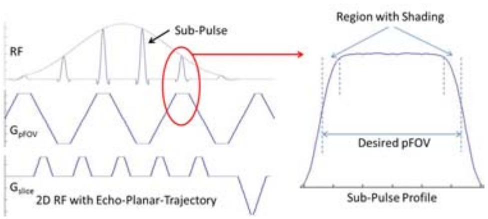

Figure 1. 2D RF with EP-Trajectory and its excitation profile in pFOV direction. Shading regions usually appear in the resulting image at both ends of pFOV, due to the RF profile imperfection.

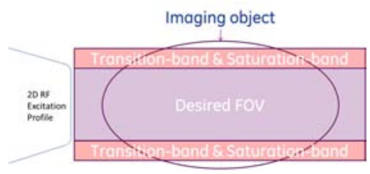

Figure 2. A pictorial demonstration of the walking saturation with 2D excitation. The spins under the transition-bands of the 2D RF are pre-saturated, which otherwise would be excited by the transition bands and wrap-around in to the desired receiving FOV.

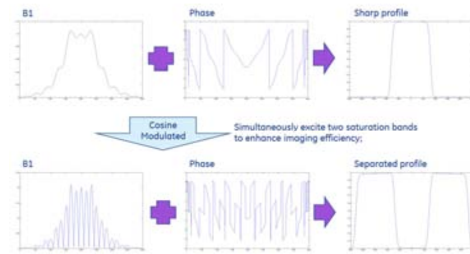

Figure 3. Quadratic phase saturation pulse with cosine modulation. Note the sharp transition bands and the simultaneous excitation of two bands.

The proposed technique achieves the excitation homogeneity in an alternative fashion. The excitation FOV is extended so that the desired FOV fall into the flat portion of the excitation profile. As shown in Fig 2, the consequential wrap-around artifact is avoided by placing a pair of saturation bands right outside the desired pFOV, such that the spins outside the pFOV (excited by the transition bands of the 2D RF) would not interfere with the signals within the pFOV. A quadratic phase RF pulse shown in Fig 3 is ideal for the saturation purpose, so that its sharp transition bands would not cause extra shading at the edges of the pFOV. To keep the best saturation results and higher imaging efficiency, the quadratic phase RF is proposed to be cosine modulated, such that two saturation bands at both ends of the pFOV can be casted at the same time. The width of a single saturation band is empirically set to 0.4 of the desired FOV, which yielded good results as presented below.

Experiments & Results Experiments with the proposed method were performed on a GE 1.5T Optix scanner both with phantom and volunteers. Clinical protocols were used but modified as adaptive to the reduced FOV. Fig 4 shows the comparison between high resolution brain DWI image obtained with regular 2D excitation and that from the proposed method. Shading on both ends of pFOV could be observed in the image using regular method (Fig 4 a), while the image is much more homogeneous with the proposed method.

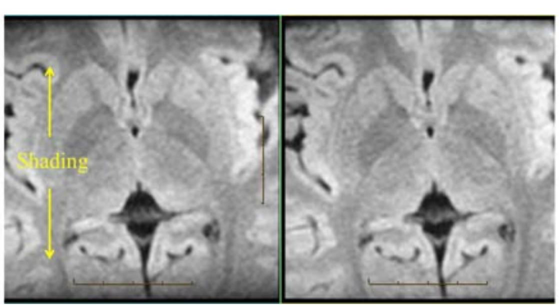

Figure 4. High resolution brain DWI images from regular 2D excitation (left) and proposed method (right). Note the shading on both ends of pFOV in the regular image.

Discussion This work presents a new method to achieve homogeneous high-resolution DWI, using a 2D excitation equipped with walking-saturation. The use of this method exceeds beyond improving image homogeneity, and it is also beneficial for Type I 2D RF design that are insensitive to system imperfections such as eddy currents (EC) and group delay between RF and gradients. Type I pulse employs only half number of sub-pulses and blip-gradients, comparing to the regular 2D RF (Type II), it therefore has more stringent demands on max B1 and gradient slew rate, and it theoretically allows only 1/4 number of slices per TR. The proposed method allows trade-offs between excitation profile and the number of slices, and hence may buy back the scan efficiency with Type I pulse. In our test, use of normal Type I RF instead of Type II pulse reduces the number of slices per TR from 16 to 4, while the Type I RF designed with proposed method brings back the slice number to 10, which is a 150% increase. Note that saturation alone was proposed for small FOV imaging yet with unsatisfactory result [(3)]. The work presented here combines the strengths of 2D RF and walking-saturation to achieve a result better than either of the method used alone.

Reference (1) S.Holdsworth, et al., AJNR 32:1274-1279 (2011). (2) Heidemann RM et al, Neuroimage 60, 967-978 (2012).
(3) Wilm B et al, MRM 57: 625-630 (2007).