Diffusion-weighted balanced-FFE imaging using eddy-current compensation

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Introduction : Diffusion imaging using single-shot DW-EPI suffers from a low spatial resolution and from the typical geometric distortions inherent to EPI. In this work, a 2D single-shot diffusion-weighted balanced-FFE sequence consisting in a diffusion preparation in front of a balanced-FFE pulse train is analyzed, as a promising DW sequence with a higher spatial resolution and without distortion artifacts. The problem of eddy currents leading to an imperfect refocusing in the diffusion preparation and resulting into strong signal inhomogeneities is assessed. Several compensation or correction strategies are investigated. Promising results are obtained for both brain and abdominal applications.

Methods : The single-shot diffusion-weighted balanced-FFE sequence is illustrated in Fig.1, in the case of a standard Stejskal-Tanner (ST) diffusion scheme. At the end of the preparation, a -90° tipup pulse flips the transverse magnetization back to the longitudinal axis. A typical problem comes from the fact that eddy-current gradients generated by the first diffusion gradient lobe can induce unwanted additional precession after the 180° pulse, resulting in an imperfect magnetization refocusing and therefore in signal loss (spatially dependent, which produces signal inhomogeneities on the image). The following compensation and correction strategies were investigated :

1. Gradient prepulse : added in front of the sequence in order to produce the same eddy-current gradient on both sides of the refocusing pulse;
2. Multi-echo (ME) scheme : two refocusing pulses are used with shorter gradient lobes (reducing the residual eddy currents). A bipolar gradient prepulse can be used with this scheme (Fig.2);
3. Phase-cycling technique : two acquisitions are performed with different axes (x and y) for the tipup pulse. In the first case the longitudinal magnetization just before the balanced-FFE pulse train is proportional to cosφ (dephasing angle due to eddy currents), in the second case to sinφ. A final image is constructed from the square root of the sum of squares of the two image intensities [1].

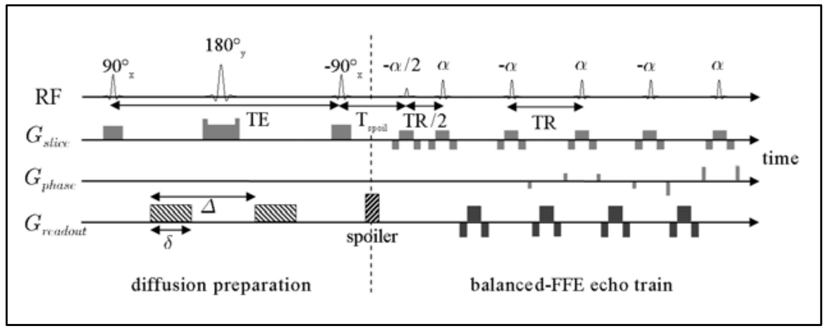

Fig.1 : Diffusion-weighted balanced-FFE sequence (Stejskal-Tanner preparation : the b-factor is given by $b = \gamma^2 G^2 \delta^2 (\Delta - \delta/3)$*).*

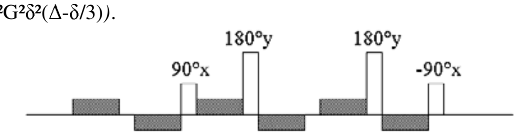

Fig.2 : Multi-echo scheme (with a bipolar gradient prepulse).

Both phantom and in-vivo experiments were performed on a Philips Gyroscan Achieva 1.5T, using ST and ME shemes with and without gradient prepulse. A 256² acquisition matrix was used (f.a.:45°, TR/TE~3/1.5ms) with a modified low-high trajectory (pairing technique [2]). The standard balanced-FFE image, the b=0 image and the diffusion-weighted image were acquired in three dynamic scans.

Results : Fig.3 shows ST and ME experiments performed in phantoms, for b=1000 s/mm². Signal inhomogeneities are clearly visible (arrows) on the ST image without gradient prepulse. The best result is obtained with the ME scheme used with a bipolar gradient prepulse. Fig.4 shows a b=100 s/mm² ME image (with prepulse) compared to EPI : the spatial resolution is clearly improved and there is no distortion artifact. Fig.5 shows a b=800 s/mm² ST experiment. As the gradient prepulse was not able to totally remove the signal inhomogeneities, the RF phase-cycling technique was used (final image). The result is promising, although there still remain some signal inhomogeneities. Finally, Fig.6 shows a b=100 s/mm² ME experiment (and corresponding b-FFE and b=0 images) performed with the bipolar gradient prepulse. The good quality of the image shows a perfect suppression of the liver vessels, which is a desired feature for better detection of hepatic lesions (not shown here).

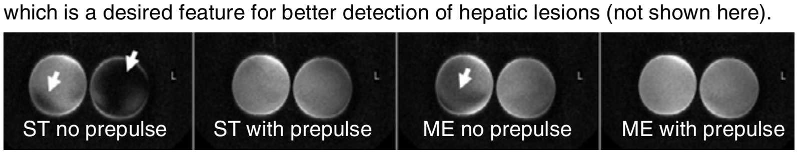

Fig.3 : ST and ME phantom experiments (b=1000) with and without the gradient prepulse.

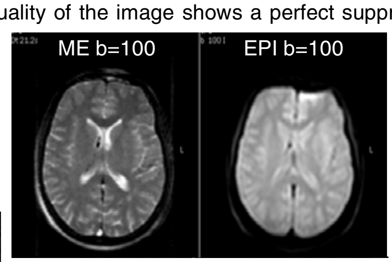

Fig.4 : Comparison between ME b=100 s/mm² and EPI b=100 s/mm² images. The ME image shows an improved spatial resolution and no distortion.

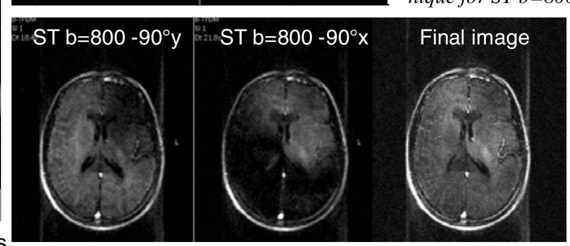

Fig.5 : Phase-cycling technique for ST b=800 s/mm².

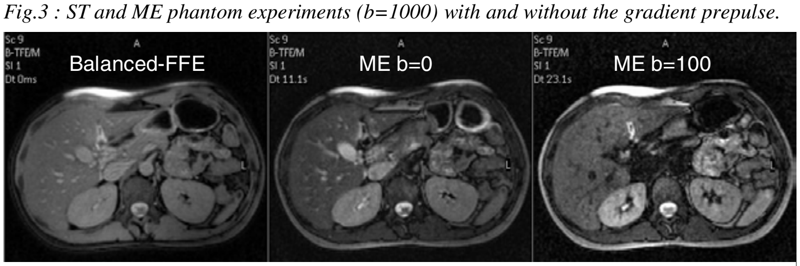

Fig.6 : ME experiment (b=100 s/mm²) in the abdomen.

Conclusions : High resolution diffusion-weighted images free of distortion artifacts can be obtained using a single-shot diffusion-weighted balanced-FFE sequence. For low b-values, the different eddy-current correction or compensation strategies tested in this work were able to remove the eddy-current artifacts (signal inhomogeneities due to an imperfect refocusing). For high b-values, the signal inhomogeneities are difficult to remove. Furthermore, an imperfect refocusing can also be caused by coherent motion and therefore some bulk motion compensation strategies need to be investigated.

References : [1] Thomas DL. MRM 39:950-960 (1998); [2] Bieri O. MRM 54:129-137 (2005).