Eliminating image shading in 3D FSE with hybrid RF

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Introduction 3D fast spin echo (FSE) is widely used in both routine diagnosis and clinical research. In order to reduce the effects of T2 signal decay [1], the conventional slice selective refocusing RF may be replaced by much shorter hard pulses and using flip angle modulation scheme may effectively reduce the T2 decay effects. The downside of this approach, however, is the non-selective nature. As a result, the non-selective 3D FSE has been only restricted in regions such as brain and knee where little out-of-FOV wrap around is expected. Hybrid 3D FSE employs a selective excitation together with a series of non-selective refocusing pulses that enables its application in other regions that is subject to FOV wrap around. However the hybrid 3D FSE is sensitive to eddy current [2], which may lead to severe shading for regions that is distant from the magnet center. In this work, we propose a modification to the hybrid 3D FSE that allows the shading effect to be effectively removed and also likely achieve a reduced echo spacing (ESP).

Methods **Fig.1a** depicts hybrid 3D FSE. It can be seen that the first excitation pulse is slice selective while all the refocusing pulses are non-selective, in this way the minimal ESP is constrained by length of the selective RF and the pre-phaser (length of the hard RF may be ignored). The close proximity (often touching) of pre-phaser and the first refocusing pulse makes the first refocusing RF very vulnerable to the short-term eddy current induced by the pre-phaser that effectively acts as a slice selecting gradient, which would consequently contaminate the following echoes. This causes image shadings in regions distant from the magnet center as shown in **Fig.2a**. As a simple proof, if the ESP is enlarged, the shading would be much reduced as shown in **Fig.2b**; however even if an enlarged ESP if the pre-phaser is moved closer to the first refocusing RF, the same shading is seen again, as **Fig.2c**. In the modified 3D FSE, we propose to shift the position of pre-phaser to post of the first refocusing RF, as shown in **Fig1b**. In this way the distance between the pre-phaser and the following refocusing RF is increased as the minimal ESP is no longer counting of the length the pre-phaser, rather determined by either the length of the selective RF or the length of the readout gradient, whichever is shorter. Hence the effects of short term eddy currents from the pre-phaser are much weakened for the refocusing RF due to the increased gap, and also a reduced ESP may be obtained. However in order to suppress the likely formed stimulated echoes, the first refocusing pulse needs to be 180. This modification shares similar nature to that proposed in [3], which was used to reduce effects of flow artifacts rather than eddy current.

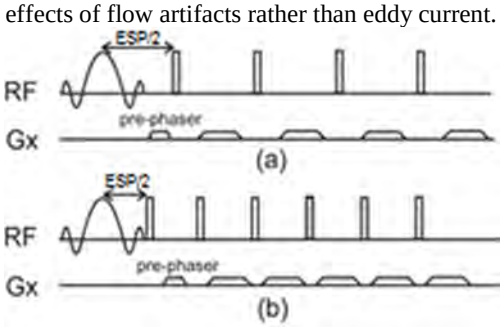

Fig. 1 (a) original and (b) modified hybrid 3D FSE

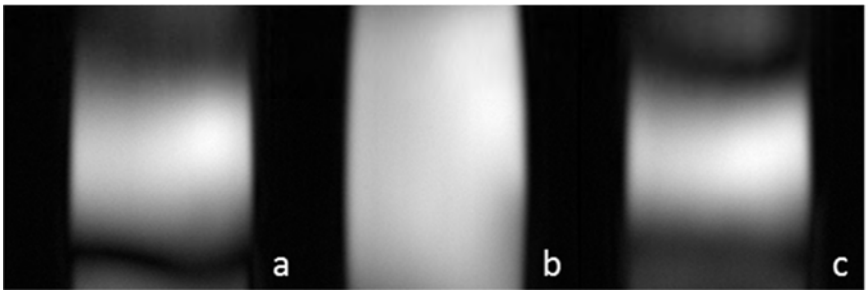

Fig. 2 image shading with (a) original (b) increased ESP (c) reduced pre-phaser gap 3D FSE

Experiment and results The proposed modification was implemented on a GE 1.5 T scanner. A healthy volunteer has been recruited for the experiment and consent form was obtained beforehand. Sagittal acquisitions of the volunteer's knee using the original and modified hybrid 3D FSE sequence with identical parameters: FOV = 16cm, Slice Thickness = 1.4mm, TR = 1500ms, TE = 26.0ms, ETL = 70, Matrix Size = 224*224, RBW = 41.67 kHz. The results are shown in **Fig.3**. It is seen that the image homogeneity is much improved using the modified 3D FSE sequence compared to that obtained using the original hybrid 3D FSE acquisition. In addition, the minimal ESP obtainable is now 5688ms compared to that of the original case of 5928ms.

Discussion and conclusion 3D FSE with hybrid RFs is often confounded by image shading caused by imperfectly compensated short term eddy current, the image shading can be removed by increasing the gap between the pre-phaser and the first refocusing echo which will inevitably enlarge the ESP. We proposed a simple modification to the hybrid 3D FSE implementation that eliminate the potential image shading and even reduces the minimal ESP by skipping the first echo readout, which has little impacts in practice due to the long echo train used in FSE. In-vivo experiment has been made to demonstrate the performance of the proposed method. A downside of this modification is the increased vulnerability of B1 inhomogeneity, as the first refocusing pulse is required to be 180 to suppress the stimulated echoes. Further investigation is ongoing to address the potential issue.

Figure 3 knee image obtained using (a) original (b) modified hybrid 3D FSE. The improved image shading can be clearly seen.

Reference [1] Xiaohong Zhou et al, JMRI, 3:803-807, 1993 [2] Dan Xu et al, MRM, 70:1293–1305, 2013 [3] John P. Mugler et al, US2013/0342202A1