FIESTA-flex : removing banding artifacts and allowing flexible contrast in FIESTA

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Introduction Balanced steady state free precession (b-SSFP), also known as FIESTA (Fast Imaging Employing Steady sTate acquisition) is a rapid acquisition sequence that find wide applications in cardiac imaging and abdominal imaging [1]. A drawback of FIESTA is its sensitivity to field inhomogeneity that may cause abrupt signal drop out, which forms the well-known banding artifacts. Also despite its outstanding signal efficiency, FIESTA's clinical applications are still limited due to the unusual contrast offered. In this work, we suggest a modification of the FIESTA sequence that overcomes those two abovementioned shortcomings, and yet maintain the benefits of FIESTA. We refer this modified sequence as FIESTA-flex.

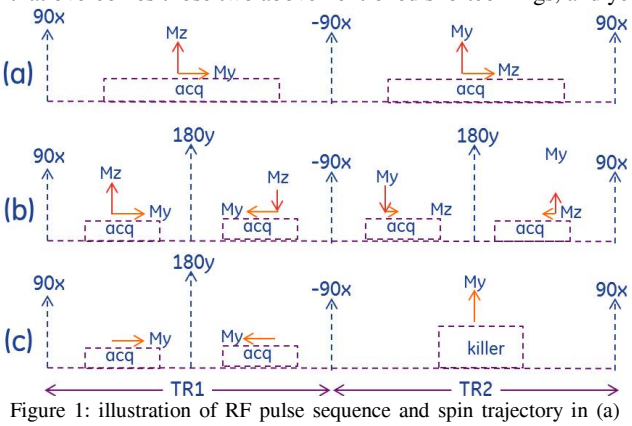

Figure 1: illustration of RF pulse sequence and spin trajectory in (a) FIESTA; (b) FIESTA with refocusing; (c) FIESTA-flex. In (c), a killer period is added after the acquisition to filter out one of the components, this adds flexibility to the signal formation by adjusting the ratio between TR1 and TR2.

Method In FIESTA, the acquisition alters in consecutive TRs between spins of My and Mz (Fig.1.a). In steady state, the T1 recovery of My in TR2 compensates for its T2 decay in TR1, and vice versa. Determined by the frequency response of FIESTA, signal phase accumulation during the TRs may cause banding artifacts in regions with high susceptibility variations [1]. An effective way to eliminate the banding artifacts is to use a refocusing pulse to refocus the signal phase (Fig.1.b).However the longitudinal components will also be flipped to negative, and its T1 recovery causes signal decay in the consequential TRs (see the shortening of My and Mz in Fig.1.b over TRs). This would result in very weak signal over time. One possible way to avoid this is to use only one spin component by adding a killer period in the following TR as in FIESTA-flex (Fig.1.c). In the steady state, the T1 recovery during TR2 equals the T2 decay in TR1.

In FIESTA-flex, it is apparent that the risk of banding artifacts is removed at the sacrifice of signal compared to FIESTA. However the killer period TR2 is flexible and may be adjusted for higher SNR efficiency or desired contrast. For instance, if TR2 is prolonged so that TR2/TR1 =2.2 (overall scan times becomes 1.6 times), the resulting SNR is doubled. Conventionally, the SNR improvement equals to square root of the scan time, which is only 1.3 times in this case. Hence FIESTA allows high return of SNR with increased time. Another benefit is the flexibility of signal contrast as compared to FIESTA: for instance, close to T1 contrast may be obtained by increasing TR2/TR1 and a smaller flip angle may also be used for the refocusing pulse instead of 180 to pronounce the T1 weighting, however at the expense of SNR.

Experiment In vivo experiments were carried out to test two aspects of the sequence using GE MR 360 1.5T scanner: 1) the sequence provides similar contrast as FIESTA and overcomes the banding issue; 2) the contrast of the sequence may be adjusted to provide other type of contrast desired. For 1), the internal carotid artery (ICA) of the same volunteer was the scanned with product FIESTA and FIESTA-flex. In FIESTA scan, shimming is performed prior to scan to optimize the field homogeneity. For 2), the TR2/TR1 ratio in FIESTA-flex is adjusted to 2 to provide a near T1 contrast, and a 3D scan was performed in the knee region and compared to that of standard 3D FSE. For fair comparison, scan time of 3D FSE was adjusted by increasing the NEX to factor ensure similar level of scan time (6:33 and 6:50 for the two cases respectively).

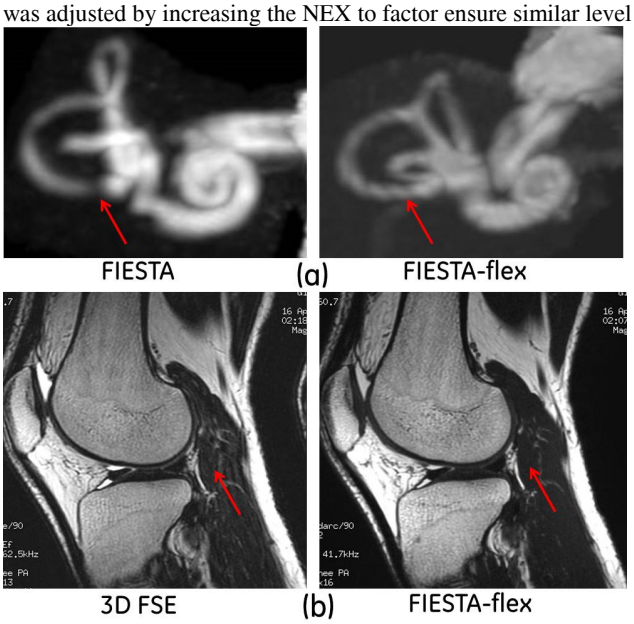

Figure 2: Comparing FIESTA-flex to (a) FIESTA and (b) 3D FSE in ICA and knee. The arrow in (a) shows the banding artifacts in FIESTA images that are absent in FIESTA-flex; the arrow in (b) shows the fine-line like artifacts seen in 3D FSE that are much less visible in FIESTA-flex.

Results The comparisons of FIESTA-flex to FIESTA in imaging the ICA and 3D FSE in imaging the knee are shown in Fig.2.a and Fig.2.b respectively. The advantage of FIESTA-flex compared to FIESTA is obvious: despite additional shimming, FIESTA still results in banding artifacts that forms discontinuity in the carotid arteries (arrow in Fig.2.a). On the other hand, the FIEASTA-flex shows a lower signal level as expected. In Fig.2.b it is seen that a very similar contrast has been achieved using FIESTA-flex as compared to T1 3D FSE. However, sharper image features are preserved in FIESTA-flex as FSE acquisition is ultimately affected by the T2 decay blurring. Also, fine-line like artifacts (arrow in Fig.2.b) haven been consistently observed in the 3D FSE images, potentially due to the signal phase errors caused by system imperfection. Such artifacts are not present in the corresponding FIESTA-flex images.

Discussion and conclusion FIESTA-flex removes the banding artifacts and allows flexibility in image contrast at the sacrifice of signal level compared to FIESTA. In vivo feasibility studies have been performed, and qualitative inspection agree with theoretical expectation. As discussed, the loss of SNR may be bought back by prolonging TR2 which however consequently changes the intrinsic image contrast. The challenge remains for finding a suitable clinical application for FIESTA-flex where the trade-off between SNR, scan time and image contrast is appropriately balanced. The use of FIESTA-flex as a 3D T1 weighted acquisition has been demonstrated successful, other potential applications may exists by exploiting its sensitivity to signal phase variation such as flow effects and diffusion weighting.

Reference [1] Bieri, et al, fundamental of b-SSFP MRIs, JMRI, 38:2-11,2013.