A Deconvolution Approach for Image Deblurring in 3DFSE Acquisition

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Introduction: Fast spin echo acquisition (FSE) (1) plays a central role in clinical MRI. A major limitation to this approach is that T2 decay across multiple acquired echoes can result in image blurring. Methods based on flip angle modulation have been reported to address this problem so that long echo train can be used to achieve high SNR efficiency in 3D imaging without excessive image blurring (2,3). In this work, we report an efficient approach to further reduce the blurring in such advanced 3D FSE imaging methods based on deconvolution of k-space.

Theory and Methods: Figure 1 illustrates the proposed algorithm. With approximated value of T1 and T2 and the given flip angle modulation, we use the Extended Phase Algorithm (4) to calculate the signal modulation profile throughout the FSE echo train. The signal modulation is then used to calculate the k-space filter for a given view ordering in 3D k-space. When parallel imaging is used, we fill the echo index for the under-sampled k-space points by linear interpolation of the echo index from neighboring k-space points. The k-space filter is truncated for SNR consideration and is smoothed afterwards. Since there is no blurring along kx direction, a 2D filter in the ky-kz plane is created and replicated along kx. We then deconvolve the acquired 3D k-space data with this filter to achieve deblurring.

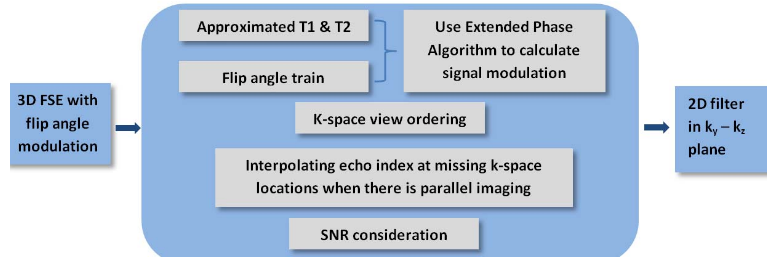

Figure 1: *The proposed algorithm for deblurring in 3DFSE with flip angle modulation.*

In vivo knee data sets were collected from a Discovery MR750 3T scanner (GE Healthcare, Waukesha, WI) using a transmit-receive 8-channel knee coil (Invivo Inc., Gainesville, FL). Informed consent was obtained for in vivo scans. The 3DFSE pulse sequence used for data acquisition was described in (5) where both a 3D anatomical image and a 3D T2 map are acquired in a single acquisition. The imaging parameters included: matrix 320x256, 44 slices, slice thickness 3mm, echo train length (ETL) 80, and echo spacing 4.3 ms. Radial view ordering was used and ARC parallel imaging (GE Healthcare) was applied along both phase encoding and slice directions.

Results and Discussion: Figure 2 shows a typical slice from an acquired 3D data set. Figure 2b) is the result when we calculate the k-space filter using a pixelwise T2 value from the calculated T2 map. We then deconvolve the 3D k-space data with this filter and repeat this process for the whole 3D k-space data. The computation time of this approach is prohibitive since 3D Fourier transforms are performed at each voxel. Figure 2c) shows the result when a single T2 value (45ms) is used to calculate the filter and then deconvolution is performed only once for the whole 3D k-space data. Note deconvolution using a single filter provides robust deblurring across the image. To compare our method to simple high-pass filtering of the k-space data, we deconvolved the k-space data with a conventional Fermi filter. The result is shown in Figure 2d). Note significant edge enhancement in this approach (white arrows in Fig 2d). However, if we match the height and shape of Fermi filter approximately to the proposed filter, we can achieve effective deblurring by deconvolving with this matched Fermi filter, as shown in Figure 2e).

Figure 3 compares the signal profile (A & C) and its Fourier transform (B & D) with different T1 (C & D) and T2 (A & B) values for a given flip angle modulation (same flip angle modulation used in in vivo scan). The Fourier transform of signal profile characterizes the level of blurring in image. Note the image blurring is very insensitive to T1 variation (D). The change of blurring is not significant with respect to the change of T2 value. This explains why a filter with constant T2 can provide robust deblurring across the FOV. To improve the quality of deblurring when T2 has a wide range cross FOV, we can calculate filters with a few discrete T2 values covering the entire T2 range and then use them to deconvolve the data.

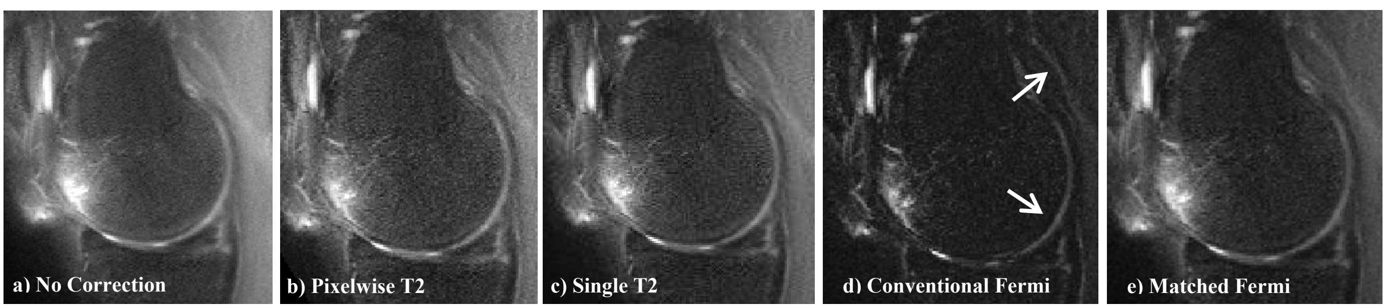

Figure 2: *In vivo results acquired using 3DFSE with flip angle modulation with echo train length 80 and echo spacing 4.3 ms.*

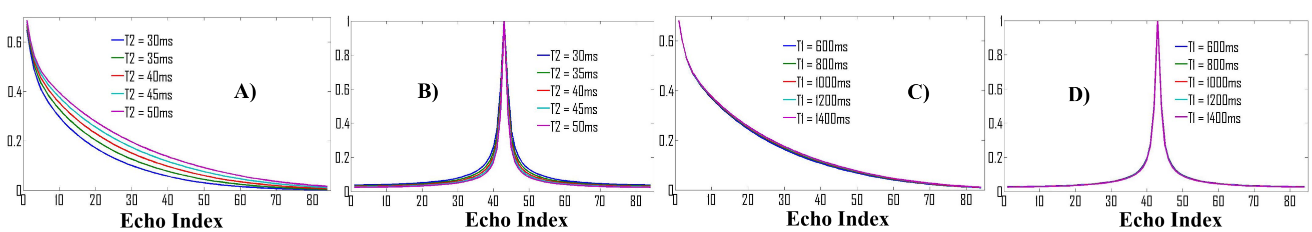

Figure 3: *Signal profile throughout the echo train and its Fourier transform with various T1 and T2. The flip angle modulation is same as that used in Figure 2.*

Conclusion: We developed an efficient deconvolution method for debluring in 3DFSE acquisition with flip angle modulation. This method requires assumption of T1 and T2 relaxation times. We demonstrated that our method is relatively insensitive to the assumed T1 and T2 for 3DFSE deblurring.

Reference: 1. Hennig et al, MRM 1986, p823 2. Mugler et al, ISMRM 2000, p687 3. Busse et al, MRM 2008 p640 4. Hennig et al, JMR 1988, p397 5. Chen et al, ISMRM 2011,