A systematic approach to design flip angle modulation in pseudo-steady-state 3D Fast Spin Echo acquisition

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Introduction: Pseudo-steady state 3D fast spin echo (FSE) acquisition (1, 2) has recently shown great promise in high-resolution 3D anatomical imaging. Flip angle modulation is used in these techniques to acquire data with very long echo trains without excessive blurring. One approach (3) to calculate the flip angle modulation of the echo train is to specify the target signal for a specific tissue with given T1 and T2, and then calculates the flip angle at each echo which yields the target signal. Another approach (3) is to specify the flip angle at control points, and then calculate the signal profile throughout the echo train by interpolating the pseudo-steady-state signal (1) at the control points, which is then used to calculate the flip angle for each RF pulse using Extended Phase Graph (EPG, 4) algorithm. The flip angle modulation provides additional dimensions of freedom to achieve desired image quality. Figure 1 demonstrates that similar T2 contrast is achieved between cartilage and fluid at very different echo times by using different flip angle modulation schemes. Different flip angle modulation can result in significant change of image contrast, sharpness, and SNR, which usually are tradeoffs among each other. Such flexibility imposes challenges but also opportunity to optimize flip angle modulation in 3DFSE to improve image quality. In this work, we propose a systematic approach to design flip angle train in 3DFSE to achieve designed image quality.

Methods and Results: Figure 2 shows the proposed method. It is impractical to optimize flip angle of each RF pulse. Instead, we specify and optimize the value of a few control parameters for a given protocol. Combined with the approximate relaxation properties of the tissues of interest and view ordering, we can calculate apodization in ky-kz (ignoring relaxation during readout). Using a rectangle object, we then quantify image contrast, sharpness, and SNR for the tissues of interest. An image metric is designed as a combination of these image qualities. The final flip angle modulation is calculated from the control parameters which are found from optimizing this image metric.

We used a T2-weighting knee protocol to demonstrate the proposed method. T2-weighting is commonly used to obtain good fluid-cartilage contrast. With centric view ordering, we use the flip angle of the RF pulse at the beginning of echo train, the center of k-space, and the end of the echo train, and the index of RF pulse where center of k-space is acquired as the control parameters. Fig 3 shows how fluid-cartilage contrast, cartilage sharpness, and SNR of cartilage vary as a function of a specific control parameter. Note the variation of these control parameters significantly impact these measured image qualities.

In vivo volunteer results were collected from a 3T MR750 Discovery scanner (GE Healthcare, Waukesha, WI). The imaging parameters include: FOV 16×16cm, TR 1500ms, ETL 60, fat sat, BW±62.5 kHz, 44 slices with 3mm thickness, image matrix 320x256, NEX 1, no parallel imaging. Figure 4 a), b), and c) show the results when the optimized metric is SNR of cartilage, fluid-cartilage contrast, and sharpness of cartilage, respectively. Note optimizing one of these image quality causing loss of the others: image blurring of cartilage is pronounced when only optimizing cartilage SNR (Fig 4a); low SNR at cartilage when only optimizing fluid-cartilage contrast (Fig 4b), and low SNR if only optimizing cartilage sharpness (Fig 4c). Fig 4d) shows the result when the metric is the sum of cartilage SNR and cartilage sharpness with equal weight when keeping fluid-cartilage contrast larger than a threshold. Note the image possessed the designed image quality.

Discussion and Conclusion: Flip angle modulation in 3DFSE provides additional dimension in 3DFSE to optimize image quality. We proposed a systematic approach to design flip angle modulation in 3DFSE to obtain designed image quality.

References: 1. Alsop et al, MRM 1997, p176 2. Busse et al MRM 2008 p640 3. Mugler et al, ISMRM 2000, p687 4. Hennig et al, JMR 1988, p397

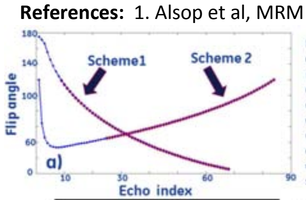
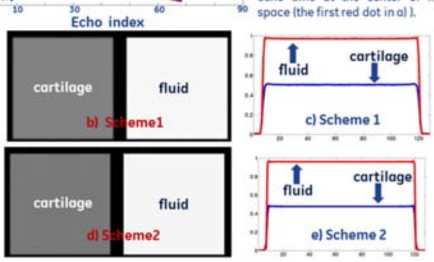


Figure 1: Two schemes of flip angle modulation in 3DFSE result in same cartilage-fluid contrast. a) flip angle train; b-e) their corresponding simulated image and cross section. Comparable cartilage-fluid T2 contrast is achieved with very different echo time at the center of k-space (the first red dot in a)).



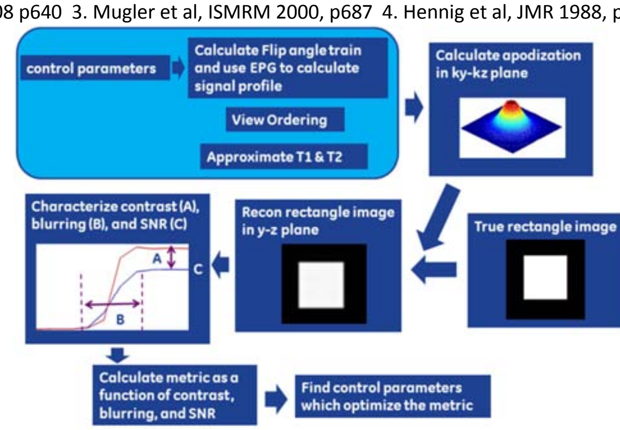


Figure 2: The workflow of the proposed approach to design flip angle modulation in 3DFSE acquisition.

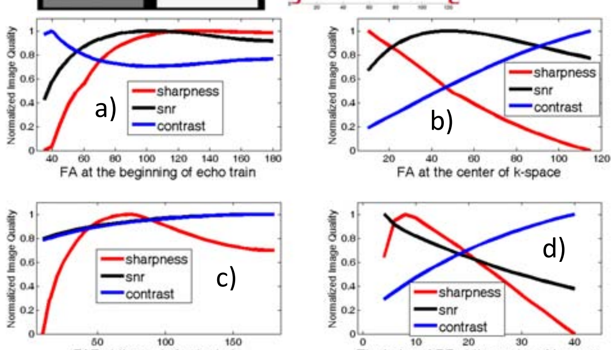


Fig 3: The calculated SNR (black), sharpness (red), and contrast (blue), as a function of the control parameters: flip angle of the RF at the a) beginning of echo train; b) center of k-space; c) end of echo train, and d) the location of center of k-space

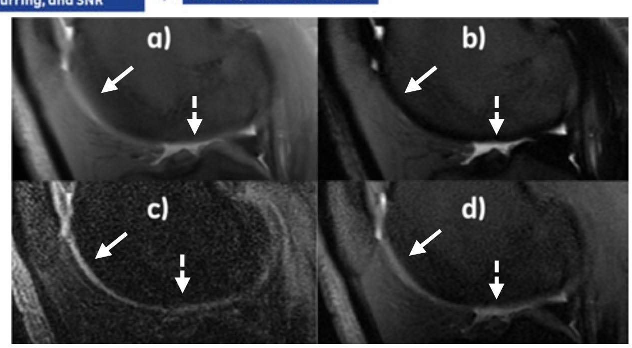


Fig 4: In vivo 3DFSE knee scan with flip angle modulation obtained from optimizing: a) SNR; b) cartilage-fluid contrast; c) sharpness; and d) combination of sharpness and SNR with same weight with cartilage-fluid contrast larger than threshold. The solid and dashed arrows show cartilage and fluid, respectively.