Collagen Signal Enhancement Using a Fast Magic Echo

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Introduction

Collagen exhibits orientation-dependent T2 and signal amplitude due to residual dipolar coupling that is not eliminated by motional narrowing (1,2). A magic echo has been used to refocus the evolution of dipolar interactions in T2-weighted imaging of joints and tendons with 2D spin echo pulse sequences (3,4). However, the magic echo uses hard RF pulses and, for multislice imaging, is more suited for 3D acquisition. The refocusing pulses in a 3D Fast Spin Echo (FSE) acquisition were replaced with a train of magic echoes. The resulting Fast Magic Echo (FME) sequence was evaluated for effectiveness in enhancing cartilage signal in T2-weighted imaging.

Methods

Assuming the excitation uses a 90_x pulse, the magic echo refocusing pulse is $90_y - \theta_x - \theta_{-x} - 90_y$ where the subscript indicates the axis of the RF pulse. The magic echo RF subpulses are all nonselective (hard pulses). If τ is the time from the effective creation of transverse magnetization (isodelay point) in the 90_x to the first 90_y, the magic echo pulse has duration 4τ and the echo refocuses at time τ after the second 90_y (TE $= 6\tau$) as shown in Fig. 1. In order to properly refocus both chemical shifts and dipolar coupling, the amplitude of the θ_x pulse (in Hz) should ideally be much larger than the amplitude of the chemical shifts (5). In practice, SAR limits the amplitude of the θ_x pulse that can be obtained with a reasonable TR. Empirical results have shown that a 250 Hz amplitude for the θ_x B1 field is sufficient to obtain reasonable dipolar and chemical shift refocusing (4). Ideally the 90_y pulses have infinitesimal width, however a width of a few hundred microseconds is the minimum attainable on whole body commercial scanners. The finite width results in residual dipolar and chemical shift dephasing.

The software on a commercial 1.5T scanner (GE Healthcare, Waukesha, WI) was modified to replace the refocusing pulses in a 3D FSE sequence with magic echoes (3D FME sequence). One drawback of the magic echo is longer echo spacing than for a conventional refocusing pulse. The value of τ is determined by the isodelay time of the RF excitation pulse and by the durations of gradient encoding and crusher waveforms that are played either prior to or after the magic echo pulse. On the scanner tested, τ was typically 3 msec or more, resulting in a typical echo spacing of 18 msec. In comparison, a conventional 3D FSE pulse sequence has a 10 msec echo spacing for a similar scan prescription. The longer echo spacing results in greater T2 modulation of k-space and greater attendant blurring or edge enhancement, depending on the k-space ordering and echo time.

Ghosting due to k-space modulation is inherent in echo train pulse sequences and is usually reduced using a phase correction. In this case the standard scanner 3D FSE phase correction was also applied to the 3D FME sequence. The phase correction adjusted the amplitude of the readout dephasing gradient and the RF phase of the magic echo pulse to minimize phase differences between the first two echoes in the echo train.

The 3D FME and conventional 3D FSE were compared using an Agar phantom to verify the expected signal enhancement from the magic echo. A quadrature transmit/receive extremity coil (Medical Advances, Milwaukee, WI) was used. Typical scan parameters for the FME were TE/TR=102/2000, echo train length = 24, 62.5 kHz bandwidth, 14 cm field of view, 3 mm slice, 16 slices, $\tau = 3$ msec, echo spacing = 18 msec, 256 x 192, 1 average, scan time 4:20. The duration of the 90_y pulses was 0.512 msec. The amplitude of the θ_x pulse was 472 Hz ($\theta_x = 900$ degrees). Similar scan parameters were used for the conventional FSE, except that the echo spacing was 10.5 msec. The magic echo and conventional pulse sequences were also compared on a volunteer using similar scan parameters to determine if cartilage signal in the knee was enhanced.

Results

The signal of the Agar phantom was enhanced by about 30% with the FME sequence compared to the conventional FSE in agreement with previous results (4). The volunteer images showed signal enhancement in cartilage, however uncorrected ghosting and blurring caused some slices for the FME to be less useful than for the conventional FSE. Figures 2 and 3 show a comparison of the two sequences.

Conclusions

A magic echo can refocus dipolar coupling, resulting in brighter cartilage and tendon signal. Because hard pulses are used, the magic echo is more suited for 3D imaging if multiple slices are acquired. T2-weighted 3D imaging is normally done using an echo train pulse sequence (FSE). The magic echo can replace the conventional refocusing pulses resulting in a Fast Magic Echo sequence. The refocusing effectiveness is limited by SAR but seems to be reasonable on a 1.5T commercial scanner. Ghosting due to echo train phase modulation is a problem that must be addressed for the pulse sequence to have practical value.

References

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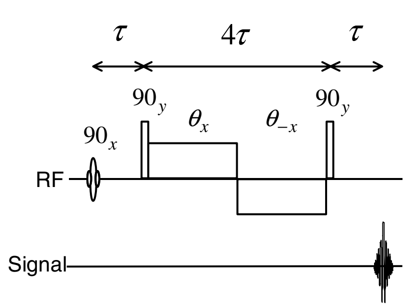

Fig. 1. Magic echo RF pulses

Fig. 2. 3D FSE scan

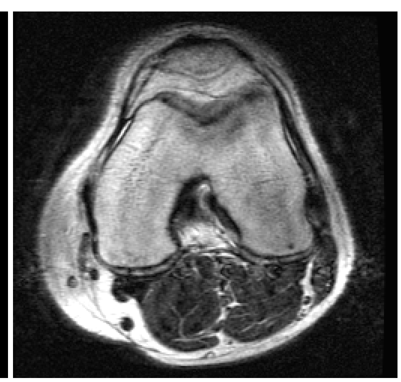

Fig. 3. 3D FME scan