Design of T_2 selective excitation pulse trains for knee imaging.

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Introduction: A change in the tissue T_2 relaxation time is a potential early marker for knee pathology (1-3). Linear combination (LC) filtering enables generation of images showing only tissues with a pre-determined range of T_2 relaxation times (4,5). However, LC filtering needs a multi-echo dataset, which requires long scan times (4,5). In this work we designed and tested a T_2 selective preparation pulse, which generates the same unique T_2 contrast images as a LC filter would, but using only a fraction of the scan-time.

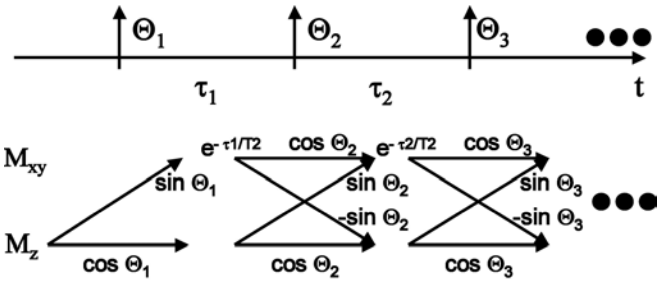

Figure 1: Each RF pulse in the pulse train, transfers magnetization between M_{xy} and M_z. At the end of the pulse train M_z will be a linear combination of different pathways. The flip angles determine the weight of each pathway in the combination while the pulse timings determine the T_2 decay. In this work, we chose the flip angles and pulse timings such that the weights of the coherence pathways match those of a T_2 selective LC filter.

Pulse Design: An LC filter is simply a linear combination of images with different echo times. The weights and echo times of the LC filter are carefully chosen to highlight T_2's of interest while suppressing unwanted T_2's (4). We designed a T_2 selective pulse train such that after the pulse train, M_z was the same linear combination as the LC filter. Fig. 1 illustrates the effect of a pulse train assuming perfect B_0/B_1 and no T_1 recovery. As refocusing pulses will be used, sensitivity to B_0 and T_1 will be minimal, however careful B_1 shimming will be needed. At the end of the preparation pulses M_z will be composed of different pathways. For example the pathway that remains in M_z is expressed as $\cos(\Theta_1)\cos(\Theta_2)\ldots\cos(\Theta_n)$, and the pathway that is tipped by the first pulse, remains in the transverse plane, then returns to M_z with the last pulse is expressed by $-\sin(\Theta_1)\cos(\Theta_2)\ldots\cos(\Theta_{n-1})\sin(\Theta_n)e^{(-\tau 1+\ldots+\tau n-1)/T2}$. Thus M_z is a linear combination of different T_2 decays just like a linear combination filter. The flip angles are equivalent to the LC filter weights, while the pulse timings are equivalent to echo times. We chose pulse timings to match those of the equally spaced echo times. We also used flip angles that matched M_z to the LC filter, the absolute value of the LC weights did not exceed unity. To improve robustness to B_0 inhomogeneities two crushed 180° refocusing pulses are added between consecutive RF pulses. The refocusing pulses are timed such that as with a Carr-Purcell-Meiboom-Gill (CPMG) sequence, all refocusing pulses are evenly spaced (6).

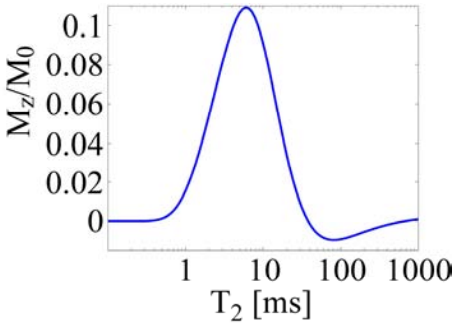

Figure 2: M_z vs. T_2 for our T_2 selective pulse. We expect good signal for connective tissue with T_2's in the range of 5-15 ms (7,8), while interfering tissues with long T_2's will be suppressed. As with LC filters there is a tradeoff between suppression and the amount of M_z that remains after the pulse train.

Methods: A T_2 selective pulse was designed using the algorithm above to highlight connective tissue with T_2's from 5 to 15 ms while suppressing other T_2's by factor 10 (1,7,8). A 1 ms 90° pulse followed the pulse train with a 2DFT readout. We used a 16cm FOV, with a 128 by 128 matrix, 10mm slices, 2 NEX and a scan time of 2 minutes. All imaging was done on a GE 1.5T Excite 11.0 MRI scanner (General Electric, Waukesha, WI), with a high-resolution 8 channel knee coil (MRI Devices, Waukesha, WI). To validate the design of the RF pulse, three phantoms were imaged. In addition to the phantoms, a healthy volunteer was imaged with the T_2 selective pulse.

Results: Three RF pulses were needed to form the T_2 selective pulse train, with flip angles -27°, 45° and 73°. The pulses were placed 18.45 ms apart. M_z vs. T_2 for the pulse train is shown in Fig. 2. MRI images with and without the pulse are shown in Fig. 3. The T_2 selective pulse suppressed the longer T_2 phantoms, as can be seen in Fig. 3(c). The images from the healthy volunteer show high signal from the posterior cruciate ligament (PCL) as expected since ligaments are known to have short T_2 components (7,8).

Discussion: Using these methods, one can design a preparation pulse train with arbitrary T_2 characteristics. Several slices can be acquired in sequence following a single preparation pulse, further improving efficiency. As with the LC filters there is a tradeoff between the pulse selectivity and SNR. This method is sensitive to B_1 inhomogeneities, which can be solved by the use of adiabatic RF pulses. T_2 selective pulse trains are a promising new method to image pathology around the knee joint.

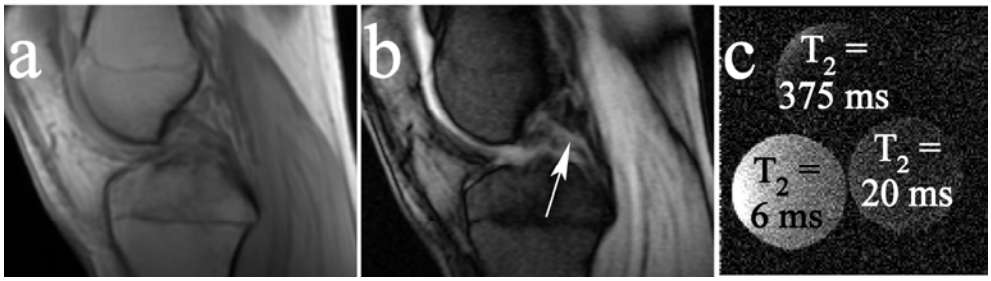

Figure 3: Images obtained by using the T_2 selective pulse. (a) Anatomic T_1 weighted image (TR/TE = 500ms/10ms). (b) With the T_2 selective preperation pulse (TR/TE=500ms/2.6ms), showing the PCL (arrow). (c) Phantom image. As can be seen in the phantom image the signal drops sharply once T_2 goes over 10 ms.

References:

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