Using the Binomial RF Pulses for Selective Excitation of the Ultra-shot T2 Component

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Introduction: Ultra-short echo imaging in the order of 100µs achievable for clinical scanners allowed the detection of protons exhibiting very short T_2 relaxation times, which is relevant many tissues, such as tendons, ligaments, or the periosteum. It was reported that a 90 degree long-T_2 suppression pulses and/or selective nulling of long-T2 components using an inversion pulse can be used for this purpose [1]. However, a simple subtraction of later echoes from the first was more frequently used to reduce the signal from long-T_2 components. In this abstract, we proposed to use the Binomial pulse train to excite only the short T_2 component and demonstrated that the new scheme indeed helped detecting fast relaxation tissues with the lower SNR that might be otherwise buried under various imaging artifacts if a simple subtraction method was used.

Methods: A Binomial pulse is a train of RF subpulses with durations or amplitudes in proportion to a binomial sequence (e.g. 1-1, 1-2-1, 1-3-3-1) that is separated by a delay between the subpulses that allows free precession of the magnetization. The pulse train is capable of create a null response at a particular frequency (e.g., used to suppress the water signal in localized proton spectroscopy). By simply setting the phase of the even subpulses 180° from that of the odd subpulses, the water will not be excited. The Bloch simulation was implemented with Runge-Kutta in Matlab for investigate the usefulness of these pulses for long T_2 suppress. For this study, the Binomial pulse is composed with a train of 100us rectangular pulse and a fixed 100us delay between the RF subpulses. T_1 is set to 1s for the simulations. The previous reported UTE sequence with spiral readout was modified by replace the excitation RF pulse with the Binomial pulse [2]. Experiments were performed on phantoms and one health subject using Siemens 7T whole-body system (Erlangen, Germany) with an eight elements Rapids Tx/Rx coil for reception and excitation. 3D isotropic UTE imaging of the resolution phantom was 128×128×128 matrix, FOV 400mm, 64 spiral interleaves and 128 rotations plane of the 2D spiral trajectory. TR was 100ms and two spiral echoes were acquired after one excitation with TEs = 70us and 2ms, respectively. Here, the nominal TE is defined as time between the center of last RF subpluse and the k-space center, which is the first acquisition data point for spiral. The spiral trajectory was designed with gradient amplitude, 24mT/m and slew rates, 140mT/m/ms. The RF flip angle was 10° for the last 100us hard subpulse in the Binomial pulse and other subpluses were scaled according to the Binomial coefficients.

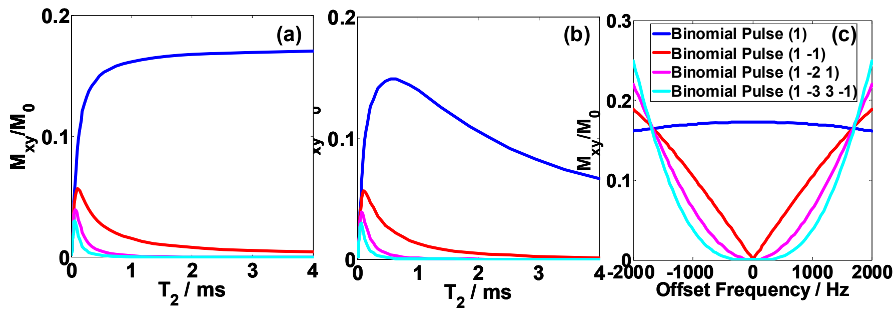

Fig. 1 Simulation results. (a) Excited transverse signal (M_{xy}) vs T_2, (b) the subtraction between TE = 70us and 2ms, and (c) M_{xy} vs offset frequency.

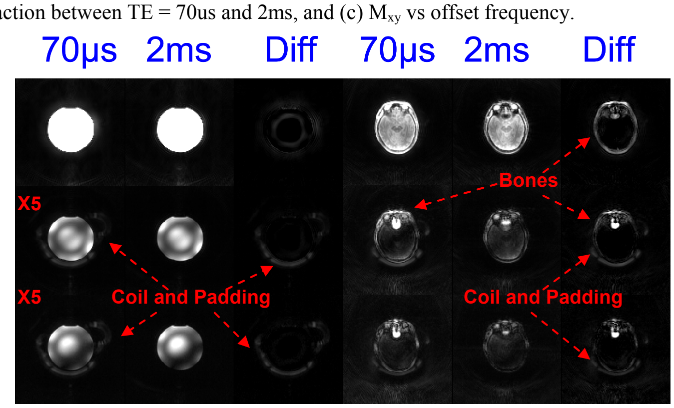

Fig. 2 UTE sequence results for phantom (left) and in vivo (right). The subtractions of the two TEs were in the 3rd and 6th column.

Results and Discussion: The Bloch simulation for a given Binomial pulse took ~30s on a Dell PC with a dual core 2.3GHz CPUs and 2.0G RAM. The results are shown in Fig.1. Fig.1a showed the transverse magnetization signal as a function of T_2 (nominal TE = 70us). As expected, a single 100us-rectangular RF pulse (blue curve) excited all components albeit with reduced excitation efficiency due to fast relaxation for T_2 up to 1ms during the RF tipping. On the contrary, the Binomial pulse only excited short T_2 components and the long T_2 components are nulled or greatly suppressed. The maximal signal occurred at 101us, 62us, and 54us for the Bionomial pulses with 2, 3, and 4 subpulses, respectively. All of the Binomial pulses clearly selectively excited only the components within a narrow region. With increased number of subpulses, the selected components shifted to the shorter T_2 range. Fig.1b showed the difference of the relative magnetization signal by subtracting the simulated signal with TE = 2ms from that of TE = 70us to match in the experiments. It is apparent that subtraction method selects wider T2 ranges (blue curve in Fig.1b) than those used Binomial pulse for selection, which is due to the long TE (2 ms) of the second echo. Fig.1c showed the simulation results for the off-resonance effects. The Binomial pulse with higher number of subpluses showed more benign behavior for the frequency offset than the lower ones for long T_2 suppress. For example, the frequency that has adequate long T_2 suppress for a (1 -3 3 -1) pulse (Cyan curve) is much wider than those of (1 -1) pulse (red curve). However, the RF energy deposition (SAR) will be significantly higher for Binomial pulse with more subpulses. The practical pulse that we found useful are (1 -2 1) or (1 -3 3 1) Binomial pulses and these were tested for both phantom and volunteers. The results of a typical slice are presented in Fig.2. The Binomial results (bottom two rows in Fig.2) have been scaled by a factor of 5. On average the Binomial pulse reduced the long T_2 signals by a factor of ~24 (in vitro) and ~11 (in vivo). For the water phantom, there is no short T_2 component except the coil and padding used [2]. The Binomial pulses (bottom two rows in Fig.2) clearly captured the signals from the coil and the padding. In contrast, the subtraction method (top row in Fig.2) failed to pick up this weak signal. This is possibly due to the unstable subtraction of the background (with imaging artifacts from strong water signal) that overshadowed this weak short T_2 signal. The in vivo results showed similar outcomes in terms of picking up the signals from padding or coils. This indicated that subtract method could be problematic for imaging the short T_2 components with low SNR. For such cases, a long T_2 suppression will be mandatory. On the other hand, both previous suppression methods and the one proposed here could be problematic if there is a large frequency offset. Thus, the logical next step is to test the method in low fields (e.g., 3T or 1.5T) that has less frequency offset than that of the 7T scanner used in this study. The low fields are also more clinically relevant.

References: [1] Robon, M.D., *et al.*, J Comput Assist Tomogr; 27; 825. [2] Zhao, T., *et al.*, Proc. Intl. Soc. Mag. Reson. Med. 17 (2009) p2662.