T_2-selective excitation with UTE imaging for bone imaging

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Target Audience: Physicists & clinicians interested in UTE bone imaging for PET, MRgFUS, MSK MRI

Purpose: 'Ultra-short echo time' (UTE) sequences are used to image short-T_2 tissues, such as bone and cartilage. Previous work has used preparation pulses [1,2] or multiple echo times [3] to create short-T_2 dependent positive contrast. Presented here is a different approach that exploits the competition between nutation and relaxation during the RF excitation to directly produce short-T_2 dependent contrast. A simple example is a rectangular 'hard' RF pulse: if the RF nutation is faster than $1/T_2$, the spins are excited, and if it is slower, they are not. Hence two rectangular pulses with the same total area—and the same nominal tip angle—can produce very different short-T_2 contrast if they have different amplitudes and corresponding durations. Subtracting images with these two pulses gives a positive short-T_2 contrast image. This can be extended to multiple pulses to resolve the short-T_2 distribution. In addition, it is compatible with sequences for which preparation pulses are cumbersome, such as 'Zero-Echo Time' (ZTE) [4,5]. Furthermore, it can be used to depict bone structure, which may be useful for musculoskeletal MR, as well as for PET/MR and MRgFUS.

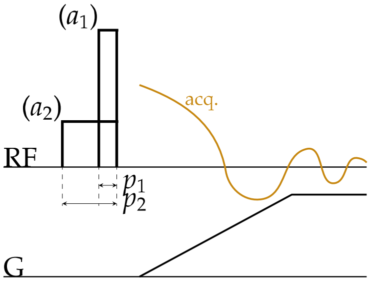

Fig. 1: Adjusting excitation pulse dimensions with fixed area gives different short-T_2 contrast with the same tip angle (e.g., used for 3D-radial UTE).

Methods: The Bloch equation dynamics can be used to calculate the effect of relaxation during an excitation pulse. Using a piecewise-constant / discrete time-step approximation for all magnetic fields (B_0 and B_1), simultaneous relaxation and precession effects are included in the computed solution. This facilitates adjusting the RF pulse width and height (i.e. duration and peak B1 amplitude; Fig. 1) to achieve a desired T_2 sensitivity in the excited magnetisation (Fig. 2), analogous to the use of echo time (TE) for control of T_2-sensitivity. Furthermore, by designing two pulses with differing sensitivity, a T_2 range of interest can be selected (Fig. 2). When such pulses are used in, e.g., a UTE imaging sequence (Fig. 1), short-T_2 anatomy of interest can be highlighted.

T_2-selectivities for different pulse dimensions were computed by Bloch simulation with a piecewise-constant approximation for all fields. Two 12°-tip pulses with different dimensions (24μT for 32μs and 2μT for 512μs; Fig. 2) were selected for having sensitivity profiles appropriate to highlight bone water with T_2 populations at 0.1ms and 0.4ms [5]. These pulses were implemented in a gradient-spoiled 3D-radial UTE imaging sequence (36μs TE, 8ms TR, 1.1mm^3 resolution) to form two sets of images with a commercially available clinical 3T scanner. The images were encoded in an interleaved fashion to diminish motion sensitivity in a difference. A later-echo (1.5ms TE) image was also acquired, with the echo time chosen to give some sensitivity to intra-voxel dephasing. Using the pulse 1 UTE and pulse 2 late echo to form a sum-normalised difference image—i.e. (|1|-|2|)/(|1|+|2|), which mitigates proton-density weighting—helps give definition to bone structure, to create an 'MR-simulated-CT' image. A CT scan (0.49 × 0.49 × 1.25mm^3) of the same patient was used for comparison.

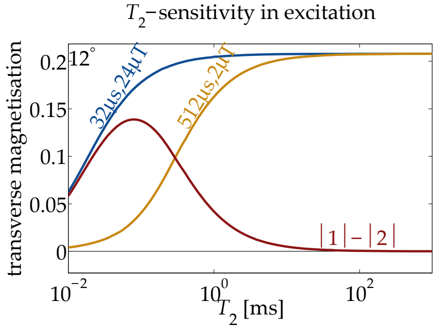

Fig. 2: T_2-sensitivities for two 12° excitation pulses are affected by their dimensions; the difference between profiles can highlight short-T_2 spins.

Results: Images acquired by the UTE sequence with different pulses show subtly different contrast, but short-T_2 features are not clear. In a difference image, the short-T_2 cortical skull bone is highlighted (Fig. 3). Longer-T_2 spins—including those resonating with significant chemical shift, such as lipid at 440Hz—are suppressed. The structures depicted compare well to CT (Fig. 4).

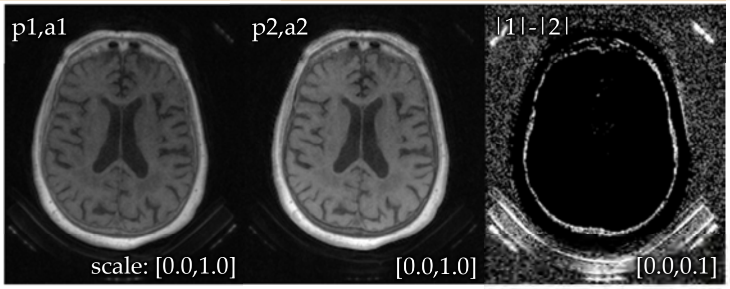

Fig. 3: Images acquired at the same TE after excitation by pulses with different T_2-selectivity and a difference image highlights a range of short-T_2 anatomy, thereby showing positive contrast from cortical skull bone. (The coil housing and padding are also visible.)

Discussion: Given the T2 ranges of interest here, off resonance precession during the RF pulse does not cause significant change in the magnitude of excitation. For a fixed tip angle, the T_2 selectivity of pulses scales like width, so off-resonance sensitivity increases if longer-T_2 ranges are targeted. Removing proton-density weighting improves the depiction of bone structure.

Conclusion: Adjusting of RF pulse dimensions is effective for generating short-T_2-selective excitation. By using multiple pulses to acquire multiple images, positive contrast for short-T_2 can be generated, and CT-like images can be created. Use of such pulses is particularly suitable for generating short-T_2 contrast in UTE and ZTE imaging sequences.

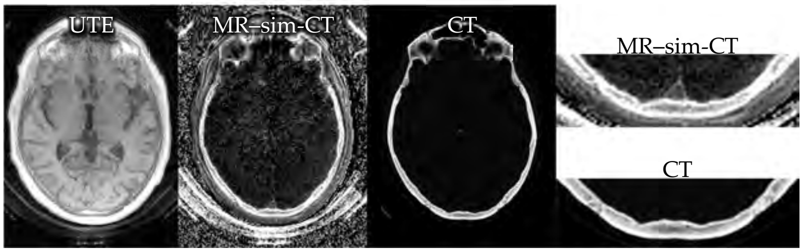

Fig. 4: Composite images from a multi-echo UTE sequence with multiple T_2-selective excitation pulses can be combined into a 'simulated' CT image, showing that similar information is available from MRI. The cortical-trabecular-cortical bone structure is clear in both.

References: [1] Pauly JM, et al. USPat. 1992;5150053. [2] Larson PEZ, et al. MRM. 2006;56:94. [3] Robson MD, et al. JCAT. 2003;27:825. [4] Madio DP, Lowe IJ. MRM. 1995;34:525. [5] Weiger M, et al. MRM. 2011;66:379. [6] Horch A, et al. MRM. 2010;64:680.