Simultaneous Quantitation of T1 and T2 Using a Novel 2D Magnetization-Prepared Multi-Slice Pulse Sequence

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Introduction In recent years numerous approaches for the efficient, accurate and simultaneous quantitation of T1, T2, and M_0 have been proposed – Ref 1 and 2 among them. Indeed, growing interest in generating synthetic MR images [2] and in "quantitative" tissue characterization continues to drive technical developments in MR relaxometry. Here we propose a novel 2D multi-slice pulse sequence that uses a magnetization preparation (mag prep) scheme to impart varying degrees of T1- and T2- weighting in a single scan – enabling simultaneous quantitation of T1, T2, and M_0. A mag prep approach enables the use of non-selective composite pulses and MLEV phase cycling to reduce the sequence's sensitivity to B0 and B1 inhomogeneities.

Background In Ref 3, Wright et. al. formulated an approach to maintain, during a subsequent 2D multi-slice acquisition, the contrast generated by a non-selective mag prep. To eliminate contrast contamination caused by T1 re-growth, two acquisitions with identical mag prep and slice acquisition order are acquired – one with its magnetization inverted immediately after mag prep (Fig 1a, inversion pulse in red) and the other without signal inversion (Fig 1b). The resulting data can then be combined to yield Eq 1 and Eq 2 (Fig 1c). By pairing acquisitions as in Fig 1, combining their acquired data per Eq 1, and then acquiring additional such pairings – each with a different mag-prep contrast weighting, a multi-shot spiral pulse sequence can be modified for quantitative T2 [4] and T1ρ [5] imaging. In the case of quantitative T2, different mag-prep contrast weightings (i.e. different effective TE's) are generated by changing - for a fixed refocusing interval - the number of refocusing pulses in the T2 Prep module [6] that precedes image acquisition.

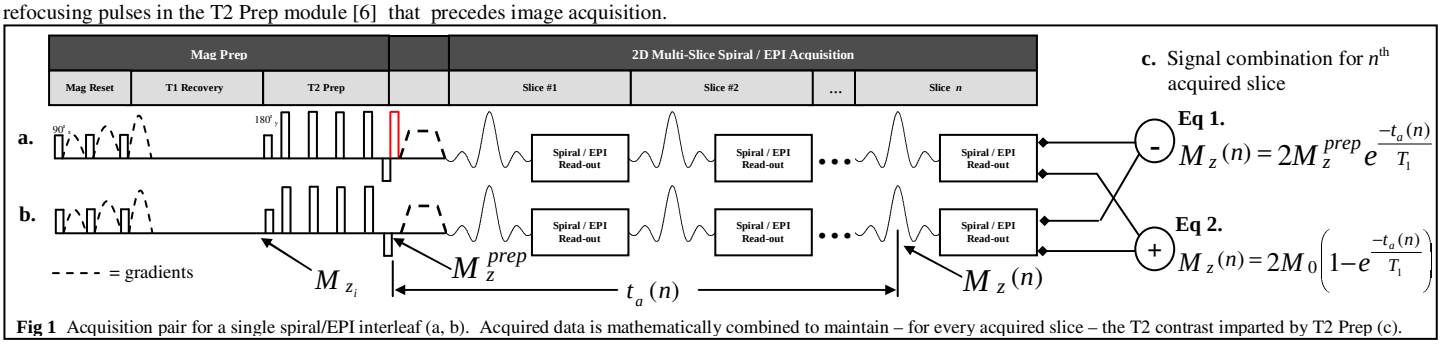

Fig 1 Acquisition pair for a single spiral/EPI interleaf (a, b). Acquired data is mathematically combined to maintain – for every acquired slice – the T2 contrast imparted by T2 Prep (c).

Theory After mag prep, the signal of each subsequently acquired slice decays with T1 (Eq 1). As long as the slice acquisiting order remains the same for all contrast weightings (as is the case for the previously proposed T2 and T1ρ techniques [4, 5]), T1's contribution to contrast remains the same for all images acquired at a given location (i.e. at a fixed t_a). To add the ability to quantitate T1, we propose a novel variation to Wright's method. To simplify the explanation, consider the case of simultaneous T1 and T2 quantitation for a single-shot acquisition. An N_{echoes} number of effective TE's and an N_{pairs} number of acquisition pairs per TE are acquired. Prescribed slice locations are sequentially partitioned into N_{pairs} number of groups. For every subsequent acquisition pair of a given TE, the slice acquisition order is circularly shifted by a group. Thus, for a given TE, each slice location is acquired at a different t_a for every acquisition pair. By combining the acquired data in two different ways, images that exhibit pure T2 decay and images that demonstrate pure T1 "decay" are generated at every slice location. T1-weighted images for a given location are derived by averaging – for each t_a - all images of a given t_a, regardless of TE. T2-weighted images for a given location are derived by averaging – for each TE – all images of a given TE, regardless of t_a. This results in N_{echoes} number of T2-weighted images and N_{pairs} number of T1-weighted images per location.

Methods A mag reset pulse followed by a fixed T1 recovery time (see Fig 1) was used to guarantee the same M_{z_i} for every acquisition regardless of spin history. The non-selective T2 Prep module [6] used composite 90_x-180_y-90_x refocusing pulses and MLEV phase cycling. Composite tipup and inversion pulses were also used. Time-efficient image acquisition was achieved with a multi-shot spiral sequence. After obtaining informed consent, the heads and knees of two healthy volunteers were imaged on a 1.5T Signa HDx scanner (GE Healthcare, Waukesha, WI). Head Protocol: FOV = 22 cm; spiral acquisition = 4096 points, 10 arms; in-plane resolution = 1 mm^2; slice thickness = 4 mm; RBW = ±125 kHz; slice locations = 20; T1 recovery time = 750 ms; N_{echoes} = 4 (2.56, 39.6, 76.7, 151 ms); N_{pairs} = 5 (t_a = 2, 137, 272, 407, 542 ms); scan time = 10 min 30 sec. Knee Protocol: FOV = 15 cm; spiral acquisition = 4096 points, 8 arms; in-plane resolution = 0.88 mm^2; slice thickness = 4 mm; RBW = ±125 kHz; slice locations = 20; T1 recovery time = 700 ms; N_{echoes} = 4 (2.56, 16.3, 30.0, 57.3 ms); N_{pairs} = 5 (t_a = 2, 138, 274, 410, 546 ms); scan time = 8 min. Quantitative T1 and T2 maps were derived by performing a two-parameter mono-exponential fit. M_0 maps were also calculated.

Results T1 and T2 values of white matter (T1: ~600-800 ms, T2: ~70-90 ms), grey matter (~850-1200 ms, ~90–110 ms), cartilage (~950-1200 ms, ~35-45 ms), and muscle (~1000 ms, ~30 ms) were within previously published ranges [2, 4]. Representative T1and T2 maps of the head and knee are shown in Fig 2 (c – h).

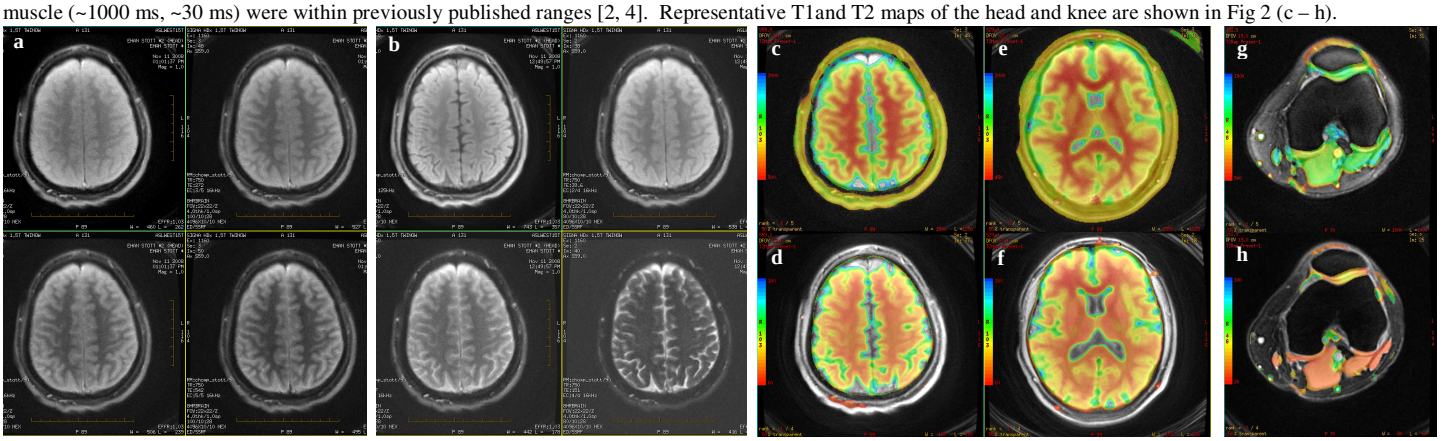

Fig 2 **(a)**: Four out of the five T1quant source images. **(b)**: All 4 T2 quant source images. **(c, d)**: T1 and T2 maps calculated from (a) and (b). **(e, f)**: T1 and T2 maps from a different slice location. Same scan as (c) and (d). **(g, h)**: Representative T1 and T2 maps of the knee.

References [1] Deoni. MRM, 2003 [2] Warntjes. MRM, 2008 [3] Wright. ISMRM 1996 [4] Gold. AJR, 2004 [5] Li. MRM, 2005 [6] Brittain. MRM, 1995