T2 Weighted Preparation with Selective Response: Contrast mechanism for dark blood imaging and arterial-venous discrimination

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Introduction

T2-selective imaging may be used to provide contrast between tissues with differing T2 values and to provide suppression of long T2 species. Conventional T2 mapping or linear combination filtering requires multiple T2 weighted acquisitions. It is possible to design a selective T2-weighted RF preparation which has the benefit of a single acquisition. Selective T2-preparation [1] has been demonstrated for imaging the meniscus of the knee with short T2. Initial results for cardiovascular application are presented using a new design approach based on adiabatic pulses and phase sensitive reconstruction. This method has potential applications to oximetry and other dark blood imaging.

Methods

The T2 selective preparation (Fig 1) uses a series of RF excitation pulses with variable flip angle and spacing which are designed to achieve the desired T2 filter response. The initial design for imaging the knee [1] used a pair of 180° hard refocusing pulses bracketed by gradient crushers. This design was modified for cardiac imaging due to presence of significant B0 and B1-field inhomogeneity, as well as flow. Flow sensitive gradient crushers were eliminated and adiabatic 180° refocusing pulses (without crushers) were used for improved B1-insensitivity [2]. Excitation pulses used either hard pulses or BIR-4 adiabatic design with variable flip angles. ECG gated, segmented imaging was performed using a SSFP readout. The selection of the preparation flip angles to achieve the desired T2 filter response for the modified design was determined by simulation by searching a discretized set of angles in an exhaustive manner. The simulation included the effects of T1-relaxation and SSFP readout which were significant in this design. In order to improve T2 contrast and provide flexibility in the filter design, the response was allowed to be both positive and negative. A phase sensitive reconstruction [3] was used to preserve the polarity of the magnetization signal. In this way, it is possible to provide a more linear response over the range of T2's expected for blood (150-250 ms) with varying degrees of oxygenation, and to provide improved contrast of myocardium and blood over a wider range of blood T2 values.
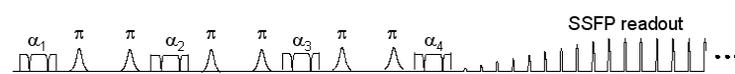

Fig. 1. T2-selective preparation with 4 adiabatic BIR4 excitation pulse excitation design, adiabatic refocusing pulses, and SSFP readout (gradient spoiler not shown).

A number of different T2-selective preparation designs were evaluated including 2, 3, and 4 RF excitation pulse designs with uniform spacing varying between 50-100 ms. Both hard and adiabatic designs were tested for excitation. An example T2 filter design response is shown in Fig 2.

Fig. 2. Example response of T2-selective preparation with 4 excitation pulse design.

The breath-held imaging protocol consisted of a T2 selective RF preparation (after trigger delay) followed by a segmented SSFP readout during mid-diastole with linear ramp flip angle for steady state approach. Typical imaging parameters with the Siemens Magnetom Avanto 1.5T MRI scanner were: bandwidth=1000 Hz/pixel, TE/TR = 1.5/3.1 ms, readout flip angle=90°, image matrix=192x108, views-per-segment=27. Proton density images used for phase sensitive reconstruction [3] and surface coil intensity correction were acquired at the same cardiac phase during alternate heartbeats using SSFP with a low readout flip angle (8°) without RF preparation. Multi-echo GRE images were acquired to estimate the fieldmaps in order to characterize effects of B0-inhomogeneity.

Results

Several examples of T2 selective images (Fig 3-5) illustrate the contrast between arterial and venous blood. These examples used 4 BIR4 pulses. Conventional bright blood SSFP images are shown for comparison. The T2 selective filter was designed such that the arterial blood (T2≈250ms) is negative and appears dark after phase sensitive reconstruction while the venous blood (T2≈150ms) is positive appearing gray. The contrast to noise ratio (CNR) between arterial and venous blood was measured to be in the range 20-40 (between LV and RV) implying a T2 precision of 2.5 to 5 ms.

Discussion

T2-selective imaging has been demonstrated for cardiovascular application to provide contrast between venous & arterial blood and has the potential for dark blood morphological imaging as well as oximetry, provided that it can be calibrated with sufficient accuracy. Additional potential applications include coronary angiography, vessel wall imaging, and dark blood edema imaging. Limitations include B0- & B1-inhomogenieties and partial volume effects. The current BIR4 design is more sensitive to B0-inhomogeneity while the hard pulses are more sensitive to B1-inhomogeneity. The adiabatic design is limited to 4 RF pulses at 1.5T due to SAR constraints.
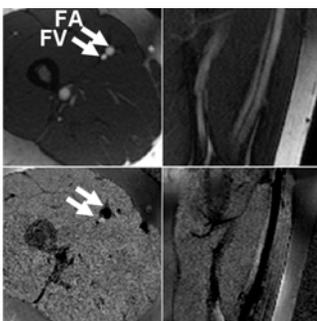

Fig. 3. Example showing femoral artery & vein in leg with conventional SSFP (top) and T2-selective preparation (bottom).
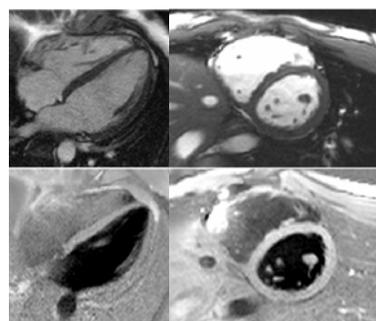

Fig. 4. Cardiac short axis & 4 chamber views with conventional SSFP (top) and T2-selective preparation (bottom).
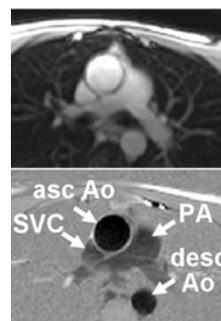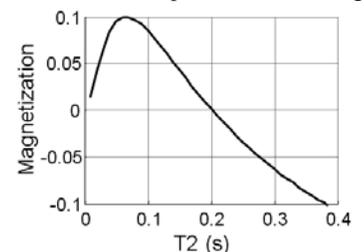

Fig. 5. Transverse view with conventional SSFP (top) and T2-selective preparation (bottom).

References

[1] Vidarsson L, et al., IEEE TMI. 2007 Jul; 26(7): 981-9. [2] Nezafat R, et al., MRM. 2006 Apr;55(4):858-64. [3] Kellman P, et al. MRM. 2002 Feb;47:372-83.