Assessment of Magnetization Transfer Effects in Myocardial Tissue Using Balanced Steady State Free Precession

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Introduction

Recently we showed that the rapid succession of high flip angle radio frequency (RF) pulses in conventional balanced steady state free precession (bSSFP) sequences causes an on-resonance magnetization transfer (MT) effect, resulting in signal attenuation in tissue with bound macromolecules [1]. The degree of the MT effect depends on the deposited power of the RF pulse train; variation of the RF power results in different MT weighting and can be used to quantify MT. In bSSFP sequences, RF power deposition can be lowered efficiently by increasing RF pulse duration and proportionally reducing RF amplitude. We applied this principle to evaluate MT in myocardial tissue.

Materials and Methods

A cardiac bSSFP sequence with adjustable RF pulse duration and flip angle was implemented on a 1.5 T MR imager (Avanto; Siemens Medical Solutions, Erlangen, Germany). Short and long axis views of the left ventricle (LV) were acquired in a normal volunteer. Per breathhold, two single phase images with different MT weightings were acquired using a segmented bSSFP sequence (spatial resolution, 1.8 x 1.8 x 8.0 mm^3; 24 segments per heart cycle). Steady state was maintained throughout the cardiac cycle, whereas data acquisition was restricted to diastole to avoid motion artefacts. In a first experiment, the effect of flip angle was investigated by varying it from 30° to 50° in steps of 5°. Two images with different RF pulse durations τ were acquired: τ=0.24 ms for the high-RF power deposition image (strong MT effect), and τ =1.7 ms for the low-RF power deposition image (weak MT effect). Repetition times (TR) for these two acquisitions were 2.9 ms and 4.4 ms, respectively.

In a second experiment, the flip angle was fixed at 45°, but pulse duration τ of the image with weak MT was varied from 1.0 ms to 3.0 ms in steps of 0.5 ms (corresponding TR, 3.7-5.7 ms). In both experiments signal intensity of the myocardial muscle was determined in regions of interest (ROI's) drawn manually and including the entire ring-shaped LV. Signal intensity of the blood pool was determined in a circular ROI placed in the LV cavity. Magnetization transfer ratio (MTR) was calculated according to

$$MTR = \frac{SI_{weakMT} - SI_{strongMT}}{SI_{weakMT}}. \qquad \text{[Eq. 1]}$$

In a third experiment, two cine data sets were acquired with a retrospectively triggered version of the same bSSFP sequence (40 reconstructed phases). The flip angle was set to 45°, and $\tau_{strongMT}$ = 0.24 ms, τ_{weakMT} = 1.7 ms (TR=2.9 ms and 4.4 ms, respectively). For each heart phase, an MTR map was generated by performing the above-mentioned calculation (Eq. 1) on a pixel-by-pixel base.

Results and Discussion

In the first experiment, variation of the flip angle (while keeping $\tau_{strongMT}$ and τ_{weakMT} constant) showed clear increase of MTR in myocardium with higher flip angles (Fig. 1a). Changes were found to be smaller towards higher flip angles and MTR seemed to approach a maximum value, as shown by the exponential fit to the data points (dashed line in Fig. 1a). This can be explained by a saturation of the MT effect at higher flip angles at short τ.

In the second experiment, an increase in τ_{weakMT} (while the flip angle and $\tau_{strongMT}$ were kept constant) resulted in higher MTR values for myocardium, with reduced changes towards longer τ_{weakMT} (Fig. 1b). This is due to weaker residual MT effects for longer RF pulses and thus larger differences between the two measurements.

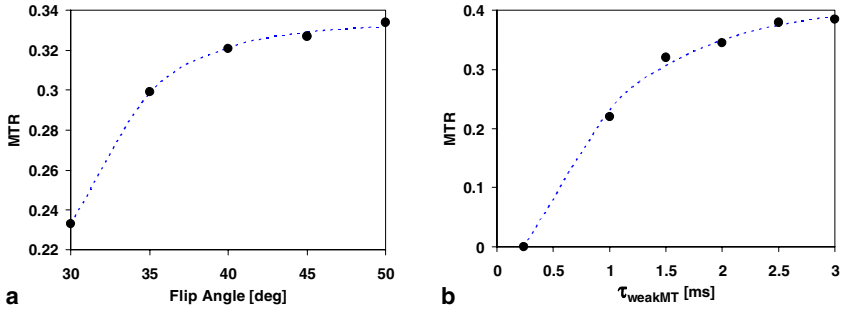

Fig. 1: *Magnetization transfer ratio (MTR) in the myocardium in dependence of a) flip angle ($\tau_{strongMT}$= 0.24 ms; τ_{weakMT}=1.7 ms) and b) RF pulse duration τ_{weakMT} (flip angle=45°, $\tau_{strongMT}$=0.24 ms). Circles: measured points; dashed line: exponential fit. Note the different scale of the y-axis in the two graphs.*

The cine sequence of the third experiment finally allowed simultaneous visualization of cardiac function and MTR maps with good homogeneity in this healthy volunteer (Fig. 2). In all experiments, blood showed virtually no signal variation (MTR=0), a consequence of the absence of MT.

Overall, higher flip angles and larger differences in TR resulted in increased MTR values in tissue with MT and thus an increased sensitivity to MT differences. However, limits in power deposition (SAR) and gradient performance, as well as the occurrence of off-resonance banding artefacts at longer TR, limited these parameters in practice to the ranges used in this study.

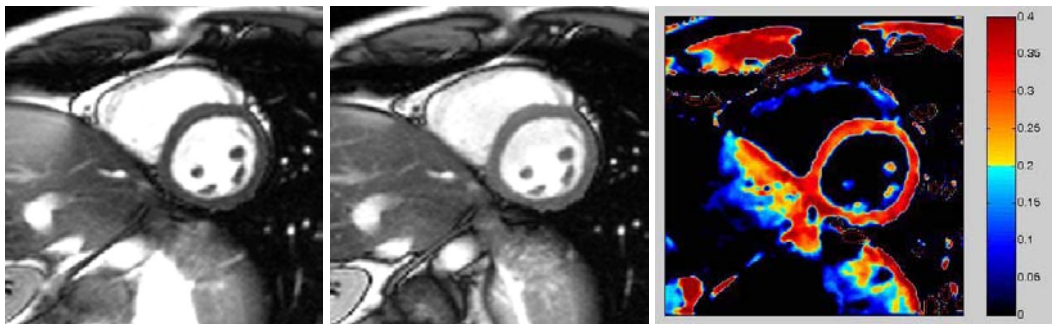

Fig. 2: *A single phase of the cine data set, acquired with strong MT weighting (left) and weak MT weighting (middle). Note the difference in signal intensity of the myocardium due to MT. Blood, on the other hand, shows virtually no difference in signal intensity due to absence of MT. The right image shows the MTR map generated from these two MR images.*

Conclusion

A novel technique to visualize and quantify magnetization transfer in the myocardium is reported. Potential applications include detection of infarcts and inflammation of the myocardial tissue. Further studies are required to fully explore the benefits of this technique.

[1] O. Bieri, K. Scheffler, On the Origin of Apparent Low Tissue Signals in Balanced SSFP, *MRM* **56**:1067 (2006)