

multiMap: A Gradient Spoiled Spin-Echo Sequence for Simultaneously Measuring B_1+ , B_0 , M_0/T_1 , T_2 , T_2^* , and Fat Fraction of a Two-Dimensional Slice

Nicholas Dwork, Adam B. Kerr, Ethan M. I. Johnson, and John M. Pauly
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1 Introduction

The multiMap sequence combines several standard techniques for quantitative imaging into a single scan. The Saturated Double Angle Method (SDAM) of B_1+ mapping [1] is an efficient method for making a B_1 map of a volume. A saturation pulse is followed by some time for recovery before an imaging radio frequency (RF) pulse is emitted. The sequence is repeated for two imaging RF pulses of different flip angles (60° and 120°) from which the Double Angle Method of B_1 mapping can be performed [2]. When imaging a single slice, the recovery time after the saturation pulse and any time after the imaging pulse before recovery are dead time (i.e., the time is not used to gather relevant information). With multiMap, we propose to fill this time with acquisitions to perform additional quantification. multiMap is a modification of SDAM when imaging one slice to simultaneously perform B_1+ and B_0 mapping; M_0/T_1 , T_2 , and T_2^* quantification; and determine the fat fraction.

2 Methods

The complete Multi-Map sequence is shown in figure 1.

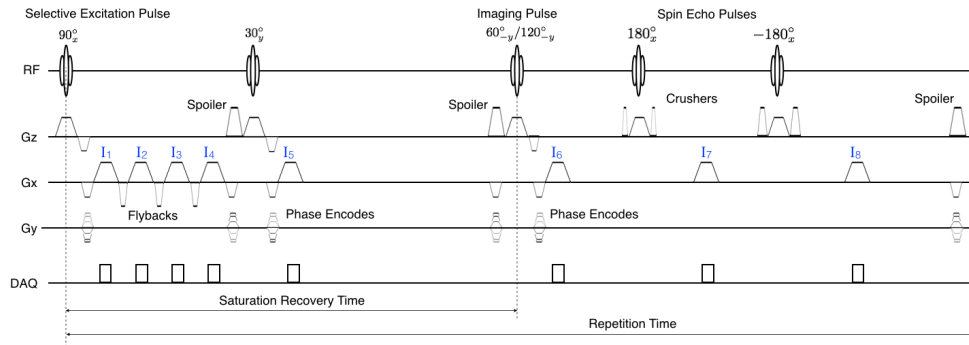


Figure 1: multiMap pulse sequence design

A two-dimensional Cartesian trajectory is used for acquisition. The saturation pulse is followed by four separate readout gradient waveforms interleaved with flyback gradient waveforms. The entire repetition is repeated twice (two segments): once with a flip angle of the 3rd RF pulse equal to 60° and a second time with a flip angle of 120° . Sixteen separate images are acquired from which the quantitative maps are determined; the acquisition associated with the j^{th} image is labeled in blue in figure 1.

Images I_6 from both segments are used to quantify the B_1 map. If we assume that the saturation pulse works perfectly, then there is no residual M_z from a previous acquisition. The M_z component then recovers during saturation. The 30° RF pulse that occurs during the saturation recovery time happens to both segments,

so the M_z at the end of the recovery time will be identical for both segments. Any remaining transverse magnetization is approximately eliminated by the spoiler at the end of the saturation recovery time. The flip angle can then be calculated according to the double angle formula[2]: $\alpha = \arccos(\sin(2\alpha)/2\sin(\alpha))$.

Off resonance, T_2^* , water, and fat are determined (similar to [3]) by solving the following optimization problem: minimize $\|(I_1, I_2, I_3, I_4) - \hat{I}\|_2$, where

$$\hat{I}_j = e^{i\Delta\omega_0 t_j} [W + F \exp(i\Delta\omega_{cs} t_j)] e^{-t_j/T_2}.$$

Here, t_j is the time associated with image I_j ; $W, F \in \mathbb{C}$; and ω_{cs} is the chemical shift frequency of fat. The fat fraction is $f_f = |F|/(|W| + |F|)$. T_2 is estimated by fitting an exponential decay to the spin echo images $I_6 - I_8$. The size of recovery duration saturation can be used to quantify T_1 . Two RF pulses are used to probe this state: a 30° RF pulse after the fourth acquisition, and the 60° RF pulse. A small 30° pulse is used to yield measurable signal while leaving the amount of recovery relatively undisturbed. Images I_5, I_6 are used to quantify M_0/T_1 . Note that $M_z(t) = M_z(t_0) + M_0(1 - \exp(-t/T_1))$. After saturation, $M_z = 0$. Therefore, $M_z(t) \approx (M_0/T_1)t$. By fitting a line to $|I_5|, |I_6|$,

$$\frac{M_0}{T_1} \approx \frac{|I_6| - |I_5|}{t_6 - t_5}.$$

M_0 and T_1 can be quantified indepently by extending the saturation recovery time and fitting and exponential to the recovery (rather than a line).

3 Results

Results were generated with a 1.5 T commercial scanner and a 62.5 kHz reception bandwidth. The repetition time was 400 ms and the saturation recovery time was 200 ms. RF chopping (alternating the phase of successive phase encode acquisitions by π) is used to push the majority of the zipper artifact to the image's edge.

Two subject types were scanned: a set of bottles with varying T_1 s and T_2 s, and a slice of a brain. The reconstructions of the bottles and brain are shown in figures 2 and 4, respectively. The quantitative maps are shown in figures 3 and 5, respectively.

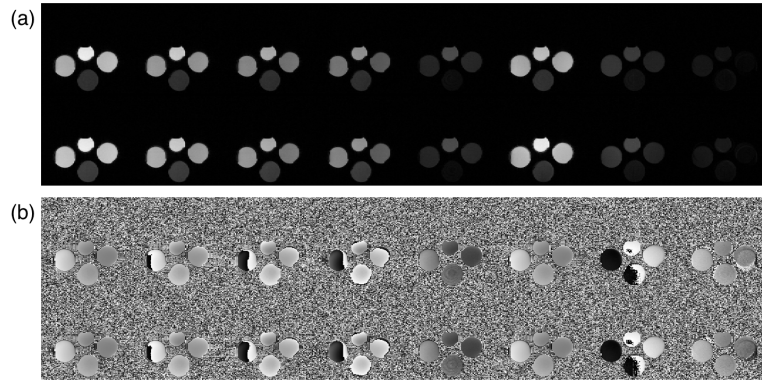


Figure 2: The reconstructions of bottles generated from the multiMap sequence; (a) are the magnitude and (b) are the phase images. The two rows are for the two different segments.

4 Conclusion

This abstract presents multiMap, a single sequence that generates many different quantitative maps. There are a large number of further improvements that could be made to this sequence. The Cartesian acquisition can be replaced with a spiral acquisition for reduced number of readouts (and a reduced total scan time). Additionally, the RF pulses and acquisitions of multiple slices can be interleaved to increase the volume of coverage. Finally, susceptibility can be quantified using the B_0 map.

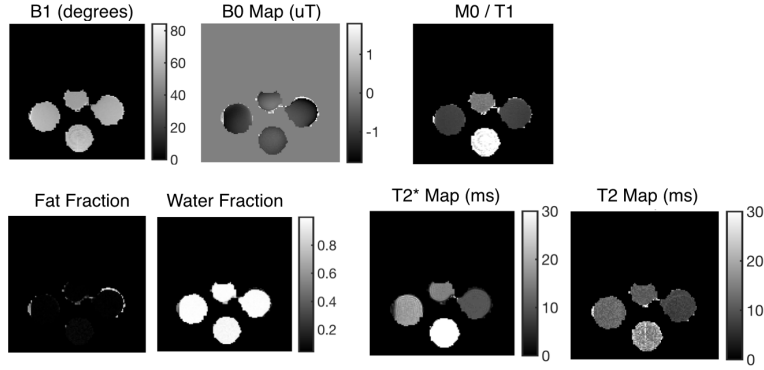


Figure 3: Quantitative maps of the bottles.

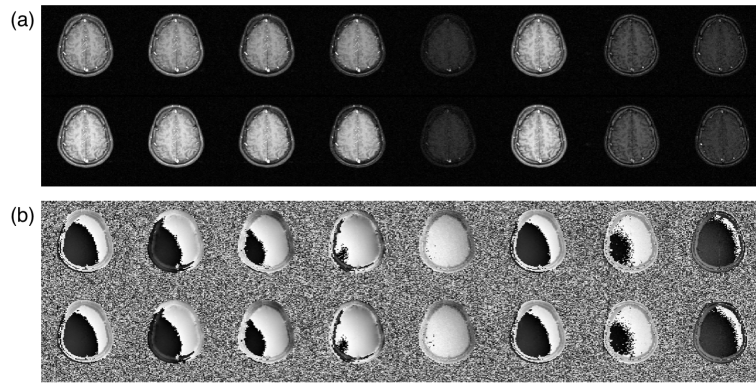


Figure 4: The reconstructions of a brain generated from the multiMap sequence; (a) are the magnitude and (b) are the phase images. The two rows are for the two different segments.

References

- [1] Charles H Cunningham, John M Pauly, and Krishna S Nayak. Saturated double-angle method for rapid B1+ mapping. *Magnetic Resonance in Medicine*, 55(6):1326–1333, 2006.
- [2] EK Insko and L Bolinger. Mapping of the radiofrequency field. *Journal of Magnetic Resonance, Series A*, 103(1):82–85, 1993.
- [3] Scott B Reeder, Zhifei Wen, Huanzhou Yu, Angel R Pineda, Garry E Gold, Michael Markl, and Norbert J Pelc. Multicoil dixon chemical species separation with an iterative least-squares estimation method. *Magnetic Resonance in Medicine: An Official Journal of the International Society for Magnetic Resonance in Medicine*, 51(1):35–45, 2004.

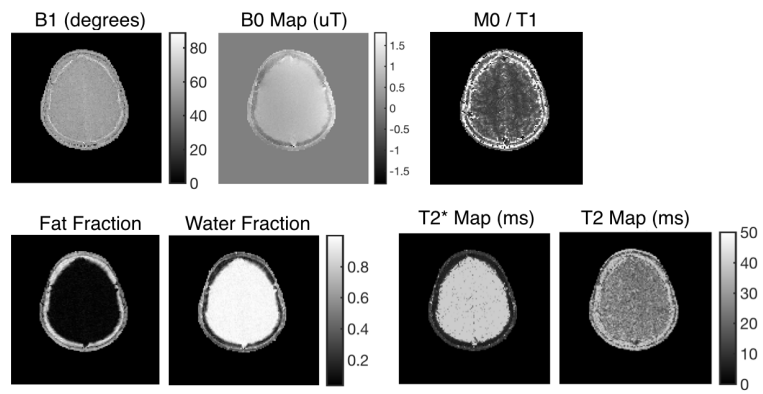


Figure 5: Quantitative maps of the brain.