Simultaneous B0- and B1-map Acquisition for Fast Localized Shim, Frequency and RF Power Determination in the Heart at 3T

M. Schär[1,2], E-J. P. Vonken[1,3], and M. Stuber[1,4]

[1]Russell H. Morgan Department of Radiology and Radiological Science, The Johns Hopkins University School of Medicine, Baltimore, MD, United States, [2]Philips Medical Systems, Cleveland, OH, United States, [3]Utrecht University, Utrecht, Netherlands, [4]Department of Electrical and Computer Engineering and Department of Medicine, Cardiology Division, The Johns Hopkins University School of Medicine, Baltimore, MD, United States

Introduction:

Cardiac MRI and MRS at 3T are challenged by the increased inhomogeneity of the static magnetic field B0 due to susceptibility. One solution to improve B0 field homogeneity is to determine localized second order shim corrections and a localized on-resonance frequency F0 based on an acquired B0-map [1]. Additionally, both numerical simulations [2] and measurements [3] have shown that also the transmit radiofrequency (RF) field B1 in the heart is more inhomogeneous at 3T as compared to 1.5T. Conventional methods to measure B1-maps, such as the dual-TR method [4], are rather lengthy and may not be appropriate for the heart because of blood flow and cardiac/respiratory motion. Recently, the saturated double angle method (SDAM) to acquire a B1-map covering the heart within a single breath-hold was introduced [5]. Applying SDAM, Sung et al reported a flip angle distribution from 34° to 63° across the left ventricle (LV) for a nominal flip angle of 60° [6]. This suggests that not only the B1 field over the LV is inhomogeneous by ±30%, but that the average flip angle (RF power setting) is about 20% lower than the requested 60°. However, erroneous RF power settings may lead to signal reduction, changes in contrast, and eventually to biased quantitative measures.

Like a B0-map based localized frequency and shim optimization, the acquired B1-map may be used to locally optimize the RF power settings. The goal of the present study was to combine the acquisition of the B0- and the B1-map into one single breath-hold for fast determination of localized shim values, F0, and RF power settings.

Methods:

The SDAM B1-map acquisition method was adapted to additionally acquire a second image for each slice with a longer echo time to simultaneously generate a B0-map (Figure 1). This results in four images per slice with all combinations of flip angles α and 2α with echo times TE1 and TE2. α-TE1 and 2α-TE1 are used to calculated the B1-map [5], whereas α-TE1 and α-TE2 are used to calculate the B0-map [1]. To reduce the deposited RF power, the flip angle of the 2α-TE2 acquisition was set to zero as this image is not used.

As the measured signal in a multi-slice acquisition depends on the excitation profile of the applied pulse shape as well as on the RF excitation angle (B1 field amplitude), the integral of the signal along the excitation profile was determined based on Bloch-equation simulations of the used pulse shape (spredrex, tBW=14.17) and for a range of RF excitation angles from 0°-180°. This was used to calculate a correction lookup table for the determination of the local B1-field.

The proposed method was implemented on a 3T Achieva scanner (Philips Medical Systems) and tested in phantoms (not shown), in the abdomen of one, and in the heart of five volunteers. For verification purposes, a dual-TR B1-map was acquired in the abdomen that took 16 minutes (3D acquisition, 400mm FOV, 79 slices, $(5mm)^3$ voxel size). The following parameters were used for the combined B0- and B1-map acquisitions: TR/TE1/TE2=22/2.85/5.15ms using the asymmetric spredrex pulse shape, α=60°, 6 slices, 5mm slice thickness, 5-10mm gap depending on heart size, FOV=$(400mm)^2$, matrix=80^2, 9 spiral interleaves with 3ms readout, T_{SR}=350-710ms depending on heart rate and RF power settings, breath-hold duration of 18 heart beats. Combined B0- and B1-map in the heart were acquired using linear auto shim and the standard RF power preparation in both, first a short-axis orientation (SA, region of interest ROI covering the left and right ventricles), and second a pseudo long-axis orientation orthogonal to the short-axis orientation (LA, ROI covering the entire heart). For each orientation localized shim values, F0, and RF power settings were determined on a PC using a modified shimming tool [1] implemented in IDL (Research Systems, Inc., Boulder, CO). The values were written back to the scanner for a second acquisition in each orientation. This process took about 1-2 minutes. In case RF power settings had to be increased, the maximum B1 amplitude in the sequence was decreased (excitation pulse duration increased, accordingly) to stay within the scanner's safety model.

Results:

Profiles of the measured B1-maps of the abdomen are shown in Figure 2 and show good agreement between the proposed method and the dual-TR method. The need for slice profile corrections is evident even when using an excitation pulse with high bandwidth. B0-map based shim and F0 determination has been well established before [1] and B0 field homogeneity (standard deviation SD over ROI) improved from 46 (62) to 25 (33) Hz for the SA (LA) orientation. Mean and SD of the measured B1 within the ROIs are shown in Figure 3. Figure 4 shows the correlation of the B1-maps acquired with orthogonal slice orientation in the heart.

Discussion and Conclusions:

The proposed method allows simultaneous acquisition of a B0- and a B1-map in the heart within one breath-hold only, enabling fast localized shim, F0 and RF power setting determination. While optimized RF power settings (zero order) should improve the imaging performance, actual higher order B1-shimming, using a multi-channel transmit system, may be needed for further improvements. The proposed slice profile correction for the B1-map seems necessary.

References:

1: Schär, MRM 2004;51:799; 2. Singerman, JMR 1997;125:72; 3: Greenman, JMRI 2003;17:648; 4. Yarnykh, ISMRM 2004:194; 5. Cunningham, MRM 2006;55:1326; 6. Sung, ISMRM 2007:355

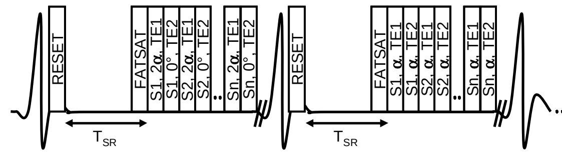

Figure 1: Schematic of the combined B0- and B1-map acquisition. The multi-slice acquisition is cardiac triggered, the magnetization is reset with an 8ms 90° BIR-4 pulse, relaxed during T_{SR}, and acquired with spiral readouts after a frequency selective fat saturation pulse. Each acquisition box in the figure denotes slice (S1-Sn), excitation angle (0°, α, or 2α), and TE (TE1 or TE2). The two shown cardiac cycles will be repeated according to how many spiral interleaves are acquired.

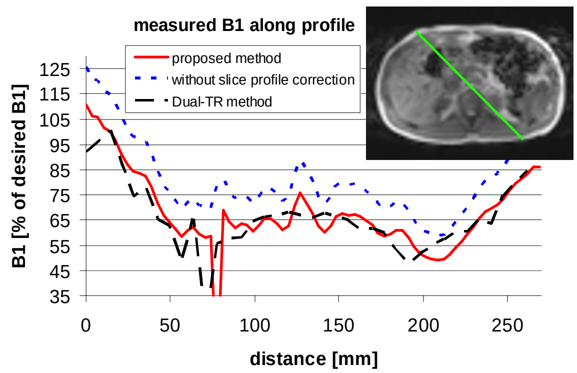

Figure 2: B1 profile along the diagonal of an axial image in the abdomen (upper right corner) in percentage of desired B1. Shown are the proposed method (solid), the dual-TR method (dashed), and the proposed method without slice profile correction (dotted).

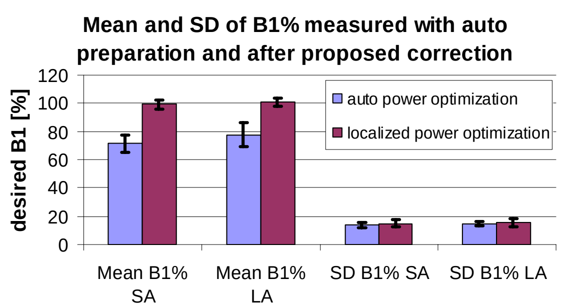

Figure 3: Mean and standard deviation (SD) of percentage B1 within the ROIs of the two acquisition orientations SA and LA acquired with the systems auto power optimization and the proposed image based localized RF power settings. Error bars show SD of 5 volunteers.

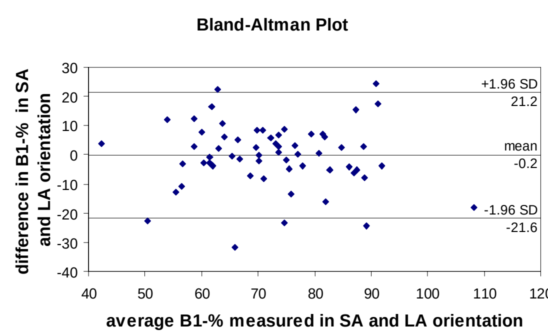

Figure 4: Bland-Altman plot correlating the B1-maps acquired in two orthogonal imaging orientations shows reasonable reproducibility. In each volunteer B1 was determined at twelve locations within the left and right ventricle in both orientations.