Absolute B1-Mapping from Repeated Varying Flip Angle RF Excitations

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Introduction

Accurate T1 measurements are an important step in quantitative studies such as absolute myocardial perfusion evaluation. T1-weighting is typically achieved by playing an inversion pulse or a saturation pulse and allowing a delay time before the read-out. In saturation-recovery, the accuracy of the T1 estimate (usually based on matching the measured signal to the Bloch equation prediction) relies on the assumption of complete initial saturation of magnetization. It was observed in numerous studies that the effective flip angle of the saturation pulse shows significant differences from the intended nominal 90° value across the field of view (1). In this study we propose a method to gauge this effective flip angle variation by calculating the actual B1 value seen by each pixel in the field of view. The method relies on the acquisition of a series of measurements at different nominal flip angles and takes into account B0 inhomogeneity effects on the effective flip angle.

Materials and Methods

We acquired a series of 40 images (Fig. 1) of a uniform cylindrical phantom of diameter 25 cm (T1 = 2.7 s) with 40 nominal flip angles *NFA* = 80.5°, 81°, 81.5°, …, 100° on a 1.5 T MR system (Avanto, Siemens), using a phased-array coil. Each image was acquired using a single hard saturation RF pulse of duration τ = 1 ms and of nominal flip angle *NFA*, then applying a spoiler of duration *TD* = 2.6 ms, and finally "reading" the residual longitudinal magnetization, for simplicity, with a single 90º RF pulse followed by an EPI center-out read-out (Single Shot EPI sequence, or SSEPI) (2). Other imaging parameters were: slice thickness = 8 mm, *FOV* = 400 x 200 mm^2, acquisition matrix = 64 x 32, *TE* = 9.2 ms. The B1-mapping method proposed here is not conditioned by the imaging method, and thus alternative imaging schemes could be used. However, the SSEPI simplifies the theoretical signal modeling. Using the B0 off-resonance frequency at pixel *(x,y)*, Δf (x,y), measured in a separate acquisition, the signal at pixel *(x,y)* is given by (3):

$$S(x,y,NFA) = M_0\left[\cos^2(\theta)+\sin^2(\theta)\cdot\cos\left(\sqrt{\gamma^2\left(\frac{NFA}{90}\cdot B_{1atNom\,90}(x,y)\right)^2\tau^2+4\pi^2\left(\Delta f(x,y)\right)^2\tau^2}\right)\right]\cdot e^{-\frac{TD}{T1}}+M_0\left(1-e^{-\frac{TD}{T1}}\right),\ \text{where}\ \theta=\tan^{-1}\left(\frac{\gamma\cdot B_{1atNom90}(x,y)}{2\cdot\pi\cdot\Delta f(x,y)}\right),$$

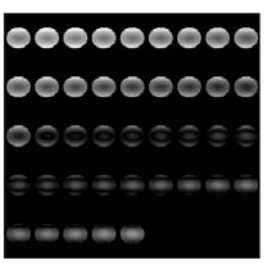

Figure 1. Transverse slices in a uniform phantom acquired with a series of nominal flip angles increasing from 80° to 100°, by increments of 0.5°.

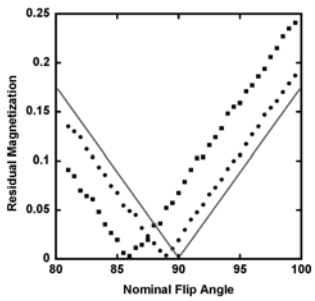

Figure 2. Measured signal values at two pixels - shown by the two different (dots and squares) "v-shaped" curves - and theoretical signal (straight line) for exact flip angle RF excitations and no B0 off-resonance effects.

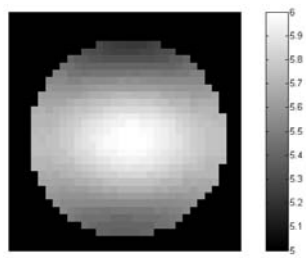

Figure 3. Absolute B1 map (greyscale from 5 to 6 μT) in a transverse section of a uniform phantom resulting when attempting to saturate the magnetization with a single nominal 90° hard RF pulse.

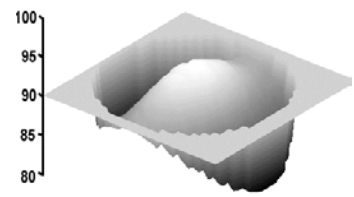

Figure 4. Corresponding *effective* flip angle variation (in degrees); the areas with no signal (outside the phantom) are shown as having 90° effective flip angle excitation, for better visual comparison.

M_0 is the thermal equilibrium longitudinal magnetization, and γ the gyromagnetic ratio. We acquired a corresponding proton density-weighted (PD) image (no saturation pulse) and normalized the 40 images acquired with the SSEPI sequence by dividing them by the PD image on a pixel-by-pixel basis; we eliminated M_0 from the above expression through normalization by the corresponding PD image. Fig. 2 shows the signal values at two arbitrary pixels for the 40 images as well as the signal given by theory with no B0 off-resonance effect and assuming that the actual flip angle is equal to the nominal flip angle. Since we have 40 *NFA* values and thus 40 *S(x,y,NFA)* measurements, for each pixel we have 40 equations and only one unknown, $B_{1atNom90}(x,y)$. We solved this over-determined system at each pixel *(x,y)* using Matlab (The MathWorks) and obtained an absolute B1 map at the considered transverse slice. The corresponding effective flip angle variation was also calculated.

Results

Fig. 3 shows such an absolute B1 map obtained in a uniform phantom by applying our method. The B1 value is larger in the center of the phantom and it drops towards the edges, showing a variation of up to 10%. Fig. 4 shows the corresponding effective flip angle variation as a surface map for better visualization of the RF excitation profile.

Discussion

The B1 and corresponding flip angle variations are important (up to 10%) and thus could account for the variability in T1 measurements observed in the literature. The determination of $B_{1atNom90}(x,y)$ can be thought of as adjusting the position of the v-shaped theoretical curve by iteratively adjusting the B1 value in the above equation until the squared error between the theory curve and the measured curve is minimized. This error minimization procedure is robust (there is a well-defined minimum for the squared error curve), and thus less than 40 nominal flip angles could be used, rendering the procedure more time-efficient for more rapid application. The B1-mapping method is robust and can be used to characterize the uniformity of the RF excitation.

References

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