B1-Gradient based MRI using a Single Surface Coil; RF-Encodig

Dominique M. R. Corteville[1], Friedrich Wetterling[1], and Lothar R. Schad[1]

[1]*Computer Assisted Clinical Medicine, Heidelberg University, Mannheim, Germany*

Introduction: In most MRI-experiments the measured signal is encoded using gradients of the static B_0-field. Alternatively gradients of the B_1-field can be used. This method is called RF-encoding. B_1-encoding techniques don't suffer from several gradient related disadvantages, such as acoustic noise, peripheral nerve stimulation, or heat dissipation. Traditionally RF-encoding is performed by modulating the magnetization along the longitudinal axis of the magnet and rotating it into the orthogonal plane by application of an additional 90° pulse [1-3]. Recent hardware improvements made it possible to achieve encoding by direct usage of the excitation pulses [4,5]. However these studies feature increasingly complex setups to achieve multidimensional RF-encoding, while investigations in simple environments are generally neglected. This study evaluates the possibilities and challenges of RF-encoding using a single transceiver surface coil, providing general information about the achievable speed and resolution, which can be used to improve more complex approaches. Sodium was chosen to outline the advantages of using nuclei with short relaxation times and strengthen the validity of the method for non-proton imaging.

Method: Since the discussed setup uses a single stationary surface coil only one direction could be RF-encoded. To achieve 2D imaging frequency encoding was used to resolve the second dimension. By modifying the RF-power in between the encoding steps, different flip-angle distributions were generated across the sample. The resulting equations were combined to a discrete encoding matrix, which was then inverted to reconstruct the image. The condition number [6] was used to determine the maximum flip angle which is required to resolve a given number of independent voxels along the encoding direction. A large number of encoding matrices were simulated in MATLAB to determine the ideal sequence.

To validate the simulation results, measurements were conducted on a Bruker BioSpec 94/20. To verify the theoretical implications various B_0-encoded measurements were conducted, investigating the effect of flip-angle alteration for the signal intensity. For these measurements a homogeneous, high-concentrated NaCl phantom was used (1cm radius, 2mol/L concentration). The same phantom was later measured using RF-encoding. To investigate the method and compare it with standard B_0-techniques the Pearson correlation between the images and a theoretical expectation was calculated. Since RF-encoding automatically takes the coil sensitivities into account quantification is directly possible. This was tested on a heterogeneous phantom (1cm radius, 50-1000mmol/L).

Results: The simulation has shown that even though the encoding matrices are generally invertible, the condition number limits the achievable resolution to about 180° per voxel. The same results were later observed in the practical experiment. This can be seen as a limitation in analogy to the Nyquist theorem for Fourier-encoding. Figure 1 shows the images of different intensity profiles measured with standard B_0-encoding techniques. It has to be pointed out that these images however are intensity weighted and do not differentiate between 90° and 270°. Clearly the lines where the signal is canceled out are visible (180°, 360°, 540°, etc.). The used setup was unable to stably provide flip-angles over 3000° thus only 16 independent voxels were resolvable.
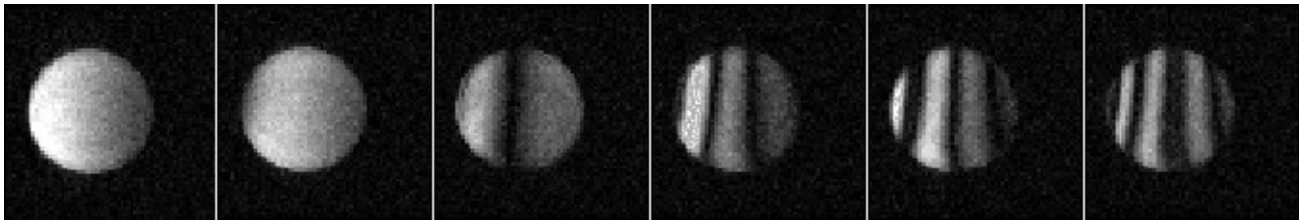

Fig. 1: Intensity profiles induced by alteration of the flip angle. From left to right: 90°, 180°, 360°, 540°, 810° and 1080° at the left side of the phantom.

Figure 2 shows the image of the same homogeneous phantom achieved both with RF-encoding and a low resolution B_0-gradient. The correlation between these images and the theoretical expectation were 93.7% for the B_0-technique and 89.7% for RF-encoding respectively. To enable fair comparison the coil sensitivity profile was removed from the B_0 measurement posterior to taking the image. Figure 3 shows the image of the used heterogeneous phantom (concentration outline in the upper left corner of the quantification right corner) and the corresponding quantification.
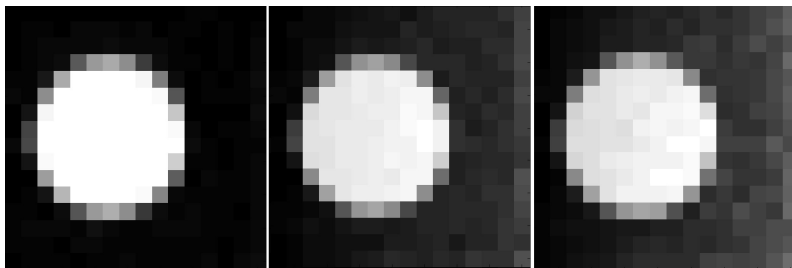

Fig. 2: Homogeneous circular phantom, from left to right:
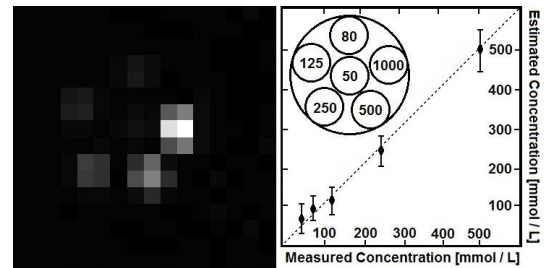Theoretical expectation, B_0 phase encoding, RF-encoding.

Fig. 3: Heterogeneous phantom,
RF-encoded picture and appending quantification

Discussion/Conclusion: As shown above the image correlation as well as the quantification capabilities of RF-encoding show good agreement with the theoretical expectation even while using a simple setup. However the currently achievable resolution is very limited. The simulation shows that with greater flip-angles higher resolutions are possible. This however implicates even less optimal SAR. The optimal solution to this are excitation fields that offer very heterogeneous field distributions (stepwise -90 and +90 degree variations) and so induce high excitation differences even at low excitation power. Furthermore a mathematical approach using suitable a-priori information and regularization techniques for post-processing is likely to increase the encoding potential of the calculated matrix and therefore increase the achievable resolution. The results of this general study can however be used to shape more suited fields and thus supply necessary basic information about the technique. While RF-encoding is still far from being usable in clinical applications the possibilities are strongly dependent on the available hardware and therefore improvements in the future are likely.

References: [1] D.I. Hoult, JMR 33 (1979) 183 [2] A.A. Maudsley MRM 3 (1986) 768 [3] G.S. Karczmar et al., MRM 7 (1988) 111 [4] U. Katscher et al., MRM 63 (2010) 1463 [5] J.C. Sharp et al., MRM 63 (2010) 151 [6] H.W. Engl, M. Hanke, A. Neubauer, "Regularization of Inverse Problems", Springer, 1996