Accurate Slice Reconstruction in 3D MRI Using Controlled Dephasing in SSFP Imaging

C. Baltes[1], M. Schaer[1], S. Kozerke[1], J. Tsao[1], P. Boesiger[1]

[1]Institute for Biomedical Engineering, University and ETH, Zurich, Switzerland

INTRODUCTION In three-dimensional magnetic resonance imaging (MRI), Fourier encoding is commonly applied to resolve distinct slices. However, adjacent slices suffer from significant signal cross-talk due to the sinc-shaped point spread function. This cross-talk is particularly problematic when the number of encoding steps is small. To overcome this problem, Hadamard encoding using multiband selective excitations was recently proposed [1], but this technique leads to significantly prolonged RF pulses. In this work, we describe a new approach to Hadamard encoding, which exploits the off-resonance properties of steady-state-free-precession (SSFP) imaging to perform the encoding. The so-called banding artifacts, which are commonly a nuisance in SSFP imaging, are taken advantage of to achieve sharp slice delineation. Each Hadamard encoding step is achieved by a different but controlled amount of dephasing during TR. In this initial feasibility study, we illustrate with simulation and phantom experiments the benefit of the proposed approach in acquiring sharply delineated slice profiles. Promising results from preliminary *in vivo* experiments are also demonstrated.

METHODS _Simulation:_ Computer simulations were performed to compare SSFP-based Hadamard encoding with conventional 3D Fourier encoding. Off-resonance precession was generated deliberately by applying the slice-select gradient to cause controlled spin dephasing (Fig. 1a). Accordingly, transverse magnetization develops alternating bands with positive and negative signal phase. This property was used to perform Hadamard encoding with four encoding steps. For the SSFP simulation, the following parameters were used: T1/T2: 817/105ms, flip angle: 60°. The resolved slice profiles were obtained after Hadamard inversion. These profiles were compared to those obtained with conventional Fourier encoding with the same number of encoding steps (Fig. 1b). _Phantom Experiment:_ The additional gradients for Hadamard encoding were incorporated into a standard SSFP sequence on a Philips Intera 1.5 T MR system. To visualize the slice profiles, controlled dephasing was applied to the read-out direction. A transverse slice of a fluid phantom containing doped water (T1/T2: 817/105ms) was acquired with different dephasing gradients according to the Hadamard matrix (scan parameters: FOV:(200x200x10)mm^3, matrix: 400^2 interpolated to 1024^2, TE/TR: 3.4/9.1 ms, flip angle: 60°, 5 signal averages). Reconstructed profiles were compared with simulation. _In vivo:_ Similar to the phantom measurement, we acquired an axial slice of the brain containing the main ventricles with the following scan parameters: FOV: (220x220x5)mm^3, matrix: 400^2 interpolated to 1024^2, TE/TR: 2.8/5.7 ms, flip angle: 60°, 5 signal averages.

RESULTS _Simulation:_ Fig. 1b shows that SSFP-based Hadamard encoding leads to both a significant reduction of side lobes and improved slice localization compared to Fourier encoding. _Phantom Experiment:_ The four slices reconstructed by SSFP-based Hadamard encoding are depicted in Fig. 2a (shaded). The measured profile was even better than the simulated profile. Comparison with the simulation showed that the actual effective flip angle was probably around 40°. _In vivo:_ As Fig. 3 shows, Hadamard inversion resulted in every 4th slice (along the read-out direction in this example) being delineated. Marginal signal contributions from adjacent regions were visible in-between the slices. Local field distortions close to the ventricles resulted in slight bending of the delineated slices. For each of the 4 sets of slices, the individual slices can be separated using other encoding mechanisms including gradient and coil sensitivity, thereby achieving a novel hybrid encoding technique.

DISCUSSION We showed in simulation that Hadamard-encoded slices were less susceptible to signal contamination from adjacent regions compared to conventional Fourier encoding. The improved localization was validated in preliminary experiments, both in a phantom and *in vivo*. Since Hadamard encoding is also a phase-encoding technique, its achievable signal-to-noise ratio (SNR) is comparable to conventional Fourier encoding. Slight SNR loss is expected from the immediate regions next to the banding artifacts. A disadvantage of this approach is the sensitivity to off-resonance effects, such as susceptibility and flow, which cause distortions to the slice profile. Nevertheless, this technique may be useful for more homogeneous regions, such as the upper section of the head, where accurate slice localization is required and the use of a minimum number of encoding steps is desirable to reduce acquisition time.

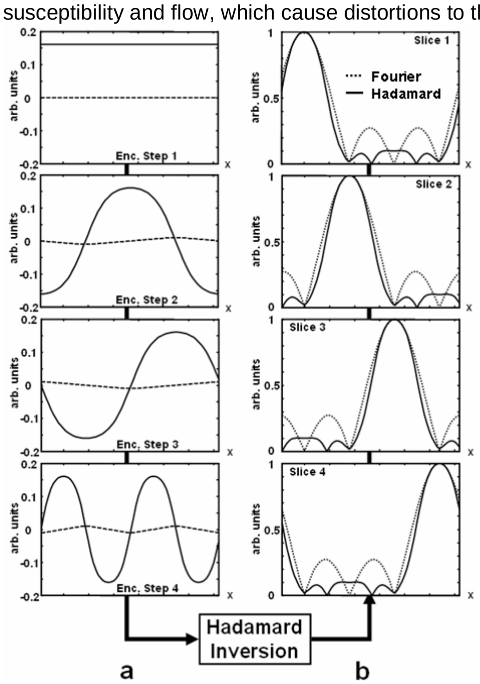

Figure 1: Simulation of Hadamard encoding using controlled dephasing in SSFP imaging. **(a)** Real (solid) and imaginary (dashed) part of the transverse magnetization for the four different encoding steps. **(b)** Slice profiles after hadamard inversion (solid) and after Fourier reconstruction with four encoding steps (dotted).

REFERENCES **[1]** Cunningham CH, et al., MRM,**48**:689-698, 2002, **[2]** Scheffler K, et al., MRM,**45**:1075-1080, 2001

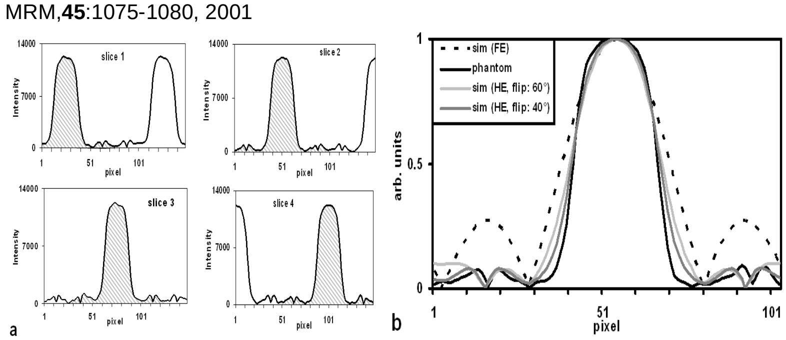

Figure 2: **(a)** Four Hadamard encoded slice profiles from the phantom. **(b)** Comparison of measured profile with simulated Fourier and Hadamard profiles

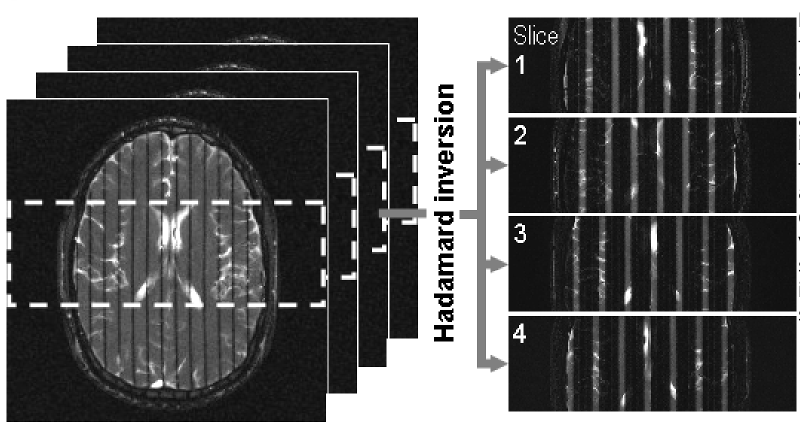

Figure 3: The four encoding steps result in distinct slices after Hadamard inversion. Local field distortions appearing closed to the ventricles cause slightly imperfect slice selection.