Factors affecting the effectiveness of a projection dephaser in 2D gradient-echo imaging

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INTRODUCTION Projection dephasers are often used for suppression of the signal of background tissues in thick-slab 2D imaging to improve the visualization of subvoxel structures, e.g. blood vessels, magnetically labeled cells and interventional devices. Despite their wide usage, literature regarding factors that govern the effectiveness of projection dephasers is very scarce [1]. In this work we aim to fill up this gap by systematically exploring –both by simulations and experimentally- the effectiveness of a projection dephaser for the prototypical case of a local non-uniformity against a uniform background.

THEORY Incorporation of a projection dephaser in a thick-slab 2D acquisition induces a phase shift of the excited spins along the slice select direction which can be modeled by a continuous Fourier transform:

$$s(\delta k_z) = \int \rho[\theta(z)]\exp[-i2\pi\delta k_z z]dz, \qquad [1]$$

where δk_z represents the dephasing gradient, $\theta(z)$ the slice profile, and $\rho[\theta(z)]$ the slice profile-weighted effective spin density across the slice. For a steady state spoiled gradient echo sequence, $\rho[\theta(z)]$ is given by:

$$\rho[\theta(z)] = \rho_0(z)\exp[-TE/T_2^*(z)]\sin[\theta(z)](1-\exp[-TR/T_1(z)])/(1-\exp[-TR/T_1(z)]\cos[\theta(z)]) \qquad [2]$$

where $\rho_0(z)$ denotes the unsaturated spin density.

MATERIALS & METHODS *Phantoms* A set of perspex cylinders (diameter 3cm, length 40cm) with copper sulphate solutions providing T_1 values between 0.1 and 1.0 s was used to evaluate the influence of the slice profile and T_1 on the quality of background suppression of projection dephasers in a uniform object. A 10-cm diameter perspex sphere with doped water ($T_1 = 1.0$ s) and an exchangeable insert was used to study the effectiveness of projection dephasers in the presence of a subslice non-uniformity. Inserts included a 3-mm perspex rod, representing a hypointensity, and a 3-mm tube with doped water with $T_1 = 0.2$ s, representing a hyperintensity. *Imaging techniques* Imaging was performed on a 3-T whole body system (Intera Achieva, Philips Medical Systems, Best, The Netherlands) with a quadrature head coil (spherical phantom) / body coil (cylindrical phantom) for signal reception. RF excitation was done with the body coil using an asymmetric sinc-gauss excitation pulse with one, two or three zero-crossings. Two-dimensional transverse and coronal images were acquired with a steady-state spoiled gradient-echo sequence with a TR/TE of 40.0/4.6 ms and flip angles of 5º, 20º, 45º, 60º and 90º. Examination parameters further included a slice thickness of 2 cm, a FOV of 256 mm^2, a scan matrix of 256^2, two signal averages, an excitation bandwidth of 5000 Hz and a readout bandwidth of 220 Hz per pixel. The scan duration was 20 s. An ensemble of dephased 2D images was created by varying the strength of the projection dephaser from 0.0 to 2.0 cm^{-1} in steps of 0.05 cm^{-1}. The spatial characteristics of the 2D slice excitation profiles were determined by a modified 3D acquisition covering 40 1-mm slices in which excitation was done by the 2D RF pulse under investigation. *Simulations* Equations [1] and [2] were used to predict the effect of projection dephasers for arbitrary slice profiles, object properties and acquisition parameters, including those specified below. A contrast parameter, $C(\delta k_z)= |s_1(\delta k_z)|-|s_0(\delta k_z)|$, was introduced to assess the differential effect of a projection dephaser in the presence (s_1) and absence (s_0) of a subslice non-uniformity.

RESULTS Experiments with uniform cylinders revealed a marked influence of the slice profile, the nominal flip angle, and the TR/T_1 ratio on the effectiveness of a projection dephaser. For a small flip angle, for instance, all samples displayed a similar response to δk_z and background suppression was easily achieved (Figs.1a-c). For larger flip angles, the response was markedly different and nulling of the background was far less easily achieved (Figs.1d-f). The observed behavior is entirely consistent with the predictions from theory (Figs.1g and 1h) and is explained by the flip angle and TR/T_1 dependent influence of saturation effects on the slice profile-weighted spin density.

For subslice non-uniformities against a uniform background, the effect of a projection dephaser was found to be much more capricious and dependent on the subslice position of the non-uniformity. For a central hypointensity and a small flip angle, for instance, the contrast $C(\delta k_z)$ was observed to be positive and to gradually decrease for $|\delta k_z|>0.5$ cm^{-1} (Figs.2a-d). For larger flip angles, repeated contrast reversals were observed (Figs.2e-h), exactly as predicted by theory (Figs.2k and 2l). Largely the same pattern of the signal varying with the dephaser was found for hyperintense non-uniformities.

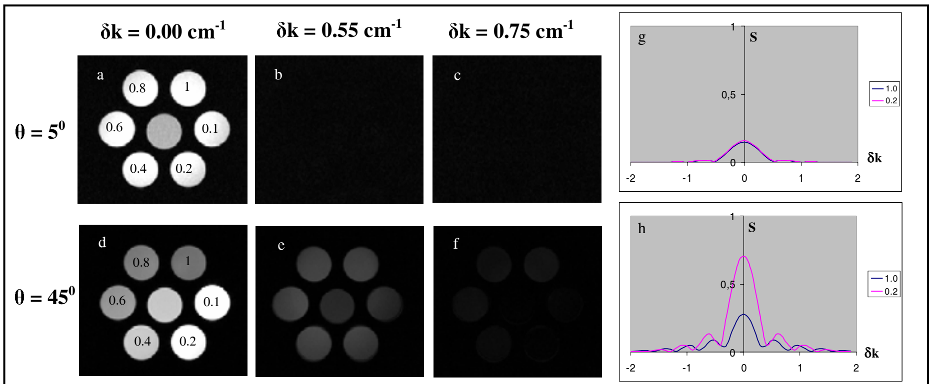

Figure 1. Observed (a-f) and predicted (g,h) influence of the flip angle on the effectiveness of a projection dephaser in suppressing the background signal from homogeneous samples with different T_1 values. (images scaled identically)

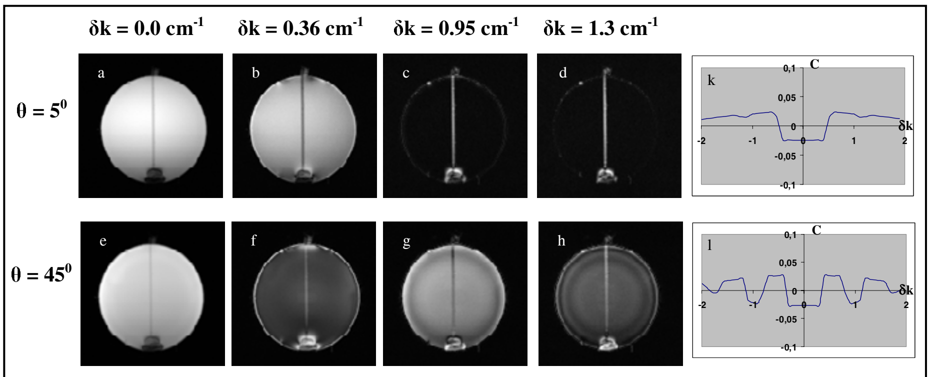

Figure 2. Observed (a-h) and predicted (k,l) influence of the flip angle on the effectiveness of a projection dephaser in highlighting a subslice hypointensity (perspex rod) within a uniform background (sphere with doped water, $T_1 = 1.0$ s).

CONCLUSION This study demonstrates that the effectiveness of a projection dephaser for suppressing the background and highlighting subslice non-uniformities is dependent on many factors, including the slice profile, the nominal flip angle, the size and intraslice position of the non-uniformity, the TR of the sequence, and the T_1 of the background. We found that using a flip angle below 1/3 of the Ernst angle makes the effect of the projection dephaser more predictable.

REFERENCES [1] Draper JN, JMRI 2006;24:160-167