A "Variable Flip Angle" Radial Steady State Free Precession Technique

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Introduction: As a very fast MRI technique that generates good tissue contrast and high resolution, steady-state free precession (SSFP) methods have drawn significant attention [1,2,3]. If SSFP data is acquired in a radial fashion, images with different contrast can be generated from the same k-space data set provided that radial views are acquired with different signal weighting. In SSFP the timing parameters, *TR* and *TE*, are fixed to a minimum to reduce artifacts due to $T2^*$ effects. The flip angle, however, can be changed without affecting the timing parameters of the SSFP pulse sequence. In this work we present a "variable flip-angle" RAD-SSFP pulse sequence and investigate its potential as a fast method that can be used to characterize tissues.

Theory: The steady state equation for SSFP can be rearranged and simplified to

$$I = S*sin(\alpha)/(R - cos(\alpha)) \qquad (1)$$
$$S = m*exp(-TE/T2)(1 - exp(-TR/T1))/(exp(-TR/T1) - exp(-TR/T2))$$
$$R = (1 - exp(-TR/T1)exp(-TR/T2))/(exp(-TR/T1) - exp(-TR/T2)),$$

where *I* is the signal intensity and *m* is a term that depends on proton density, rf coil quality, magnetic field. With images acquired at different flip angles, the *I* vs. α curve can be fitted to equation (1) to estimate the parameters *S* and *R*. Although both parameters can potentially be used to characterize tissue, *R* is purely based on the relaxation properties of tissues thus is more suitable for tissue characterization.

Methods: A "variable α" RAD-SSFP method was implemented on a 1.5T GE Signa NV-CV/i MRI scanner. The pulse sequence was designed to collect each radial view at a different flip angle covering the range α_N/N to α_N, where *N=512* was the total number of views and $\alpha_N = 45^o$. Because the flip angle was increased gradually from α_N/N to α_N in very small steps, each view can be considered to be collected at steady state. The angular ordering of radial views was designed to acquire *N=MxG* views with each group of *M=64* views distributed evenly over 2π in k-space. In order to produce partial data sets with different contrast due to flip angle, we used each group of *M* views in the center of k-space, up to the Nyquist radius. The rest of the data was added progressively from the Nyquist radius to the edge of k-space [4]. In this manner, *G=8* k-space subsets were generated, each with an effective flip angle $\alpha_{eff} = (\alpha_N/G)*(i-0.5)$, *i=1, 2, .., G*. From these subsets eight images with variable α_{eff} were reconstructed using complex filtered back-projection. The signal intensity on these 8 images was fitted on a pixel by pixel basis to equation (1) to generate the *R*-parameter maps.
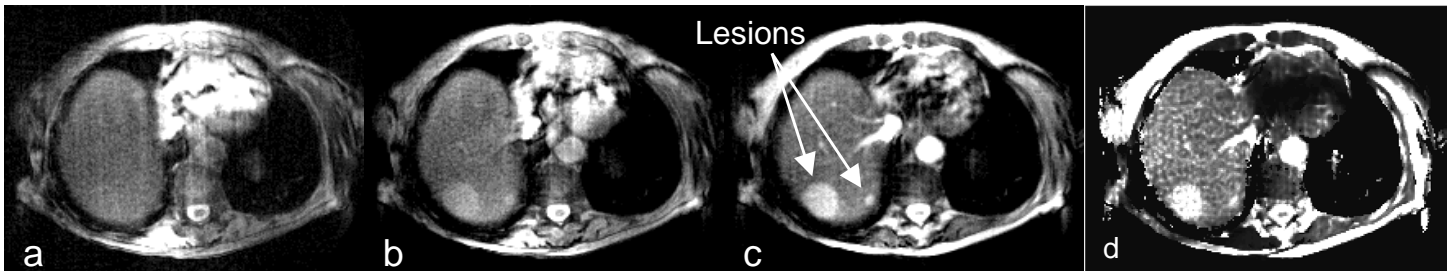

Fig 1 Images of a patient with multiple hemangiomas. Images corresponding to effective flip angles (a) 14.1°, (b) 25.3°, (c) 42.19°. (d) R-factor map. Data were acquired with 256 readout points, 512 views, BW=±125 kHz, TR=5.0 ms, TE=2.5 ms, NEX=1.

Results and Discussion: Three out of the 8 images at different α_{eff} are shown in Fig. 1a-c. From these images, we can see that high-resolution data with variable contrast can be reconstructed from a single k-space data set. Since there is no misregistration between these images, an R-factor map (Fig. 1d) can be generated. Plots of *I* vs. α curves of measured data (*symbols*) together with the fitted data (*lines*) are shown in Fig. 2 for various tissues. From these plots we can see that the measured data fits well equation (1). Also each tissue has a distinct curve and R factor (as shown in the right hand side of the legend). More importantly, there is a clear difference between the curves and *R*-factors of malignant and benign lesions. Although we only tested the method in a few subjects (*n=5*), these results are very encouraging and will be tested further in a larger group of subjects.

Conclusion: A novel "variable flip angle" RAD-SSFP method has been designed. The results show that *R*-factor maps can be derived from the images at variable effective flip angles without losing the time benefit of the SSFP sequence. These parameters can potentially be used to characterize tissues.

References: [1] Scheffler K, ISMRM, 11, 552 (2003). [2] Schmitt P, ISMRM, 11, 135 (2003). [3] Huang T, ISMRM, 11, 984 (2003). [4] Altbach MI, ISMRM, 11, 1096 (2003).
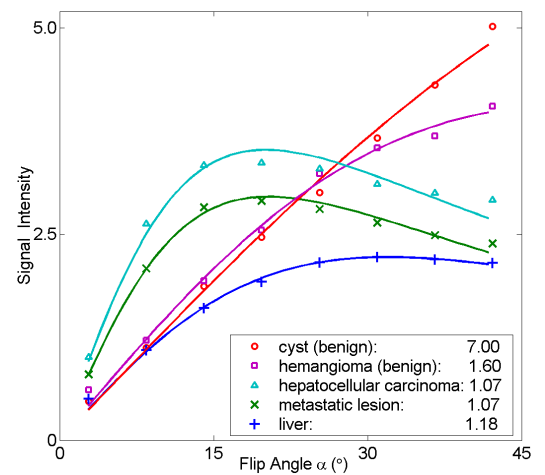
Fig 2 Signal vs. α plots of measured data (symbol) and fitted data (lines). The numbers in the legend are the corresponding *R* values. In order to show data from different patients in one graph, the signal intensity on each curve was scaled according to the maximum signal intensity of the liver on each patient.

cyst (benign):	7.00
hemangioma (benign):	1.60
hepatocellular carcinoma:	1.07
metastatic lesion:	1.07
liver:	1.18