A Noise Analysis of Flip Angle Mapping Methods

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Introduction: Methods of flip angle measurement include double angle methods using gradient-recalled echo (GRE) or spin-echo (SE) acquisitions (1,2), steady state methods utilizing two alternating repetition times ("actual flip angle" or AFI) (3), and a phase sensitive method in which flip angle is encoded in the phase of the image (4). We have analyzed the accuracy of these methods by explicit calculation of the probability density function (PDF) of the flip angle estimate for each method with noise corrupted data. The current analysis differs from a previous Monte Carlo study (5) which investigated a different phase sensitive method from the one considered here (4).

Methods: PDFs for each of the four flip angle mapping methods (dual angle GRE, dual angle SE, AFI, and phase sensitive) were simulated using the theoretical signal equations. Saturation recovery with a TR of 500ms was assumed for the dual angle and phase sensitive methods. TR's of 30ms and 150ms were used for the AFI technique, corresponding to published typical values. The flip angle estimate of the AFI method is based on averaging of six signal acquisitions relative to the dual angle and phase sensitive methods to maintain constant total acquisition time across methods. A T1 of 500ms was assumed. System signal to noise ratio (SNR)

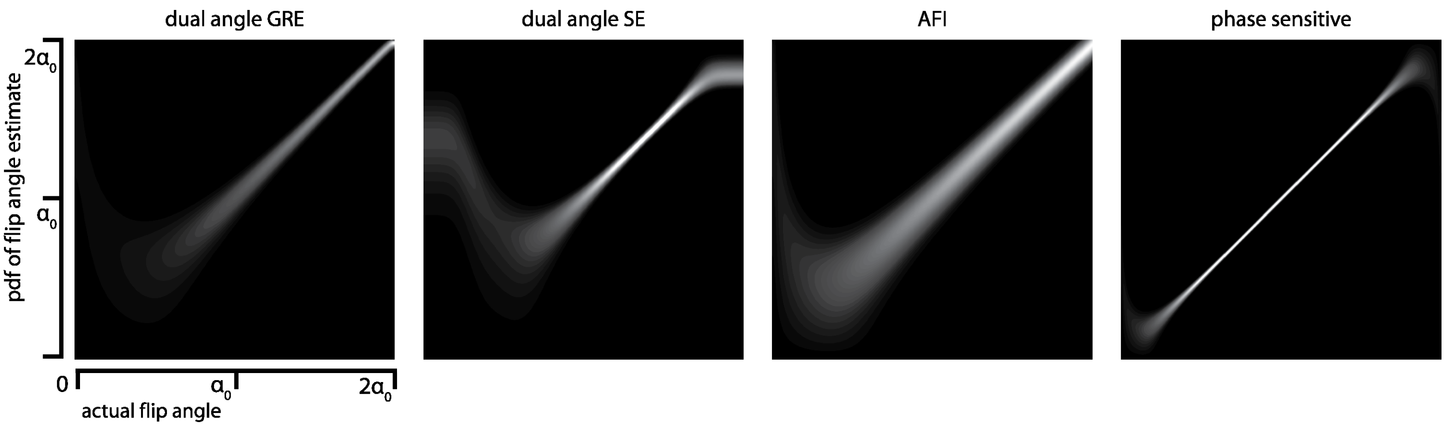

Figure 1: PDF of flip angle estimate (y axis) vs. actual flip angle (x axis) for system SNR of 50 for the four flip angle measurement methods. AFI results reflect 6-fold averaging of the measurements for the AFI method due to its lower effective TR. For the dual angle and AFI methods, $\alpha_o = 45$ degrees. For the phase sensitive method, $\alpha_0 = 90$ degrees.

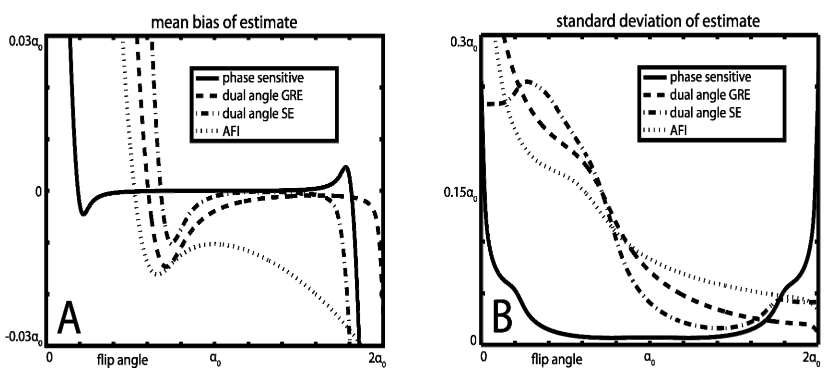

Figure 2: Mean bias (A) and standard deviation (B) of flip angle estimate for four methods of flip angle measurement.

of 50 was used, defined as the ratio of the maximum signal which could be obtained with a 90 degree excitation with infinite TR to the standard deviation of the noise. For all four methods, we have ignored the details of acquisition and focused on the intrinsic information about flip angle encoded in the observable quantity (i.e. signal ratio or image phase) for each method. The phase sensitive method measures flip angles in a range of about 0 to 180 degrees, while the other methods measure flip angles of about 0 to 90 degrees. To enable valid comparison, we have expressed the mean bias and standard deviation in terms of an angle α_0 representing the middle of the measurable range. For the dual angle and AFI techniques, $\alpha_0 = 45$ degrees, while for the phase sensitive method, $\alpha_0 = 90$ degrees. The correctness of the PDFs was verified by Monte Carlo simulation.

Results: Figure 1 shows a graphical representation of the PDF (y axis) vs. the true flip angle (x axis) for the range of 0 to $2\alpha_0$ for each of the four methods for a system SNR of 50. A perfectly accurate method would be represented by a thin diagonal line. Figure 2 shows the mean bias (panel A) and standard deviation (panel B) of the flip angle estimate for each method at SNR of 50.

Discussion: The phase sensitive method of flip angle mapping has greater intrinsic accuracy than the other methods. The dual angle and AFI methods become especially inaccurate at low flip angles.

References: **1**. Insko *et al., J Magn Reson* 1993;103:82-85. **2**. Cunningham *et al.,. Magn Reson Med* 2006;55(6):1326-1333. **3**. Yarnykh*, Magn Reson Med* 2007;57(1):192-200. **4**. Morrell, *Magn Reson Med* 008, 60(4), 889-94. **5**. Wade *et al., 15th Meeting ISMRM*, 2007, p. 354.