Significance of Excitation Flip Angle in Balanced SSFP Cine Cardiac Imaging

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Introduction
Balanced-SSFP (B-SSFP, TrueFISP) has gained a position as the almost exclusively used pulse sequence for cine based cardiac function scanning. The sequence is fast due to a very short TR and the signal-to-noise ratio is high compared to spoiled pulse sequences and is independent of TR. Theoretically, the signal-to-noise ratio in the B-SSFP sequence

$$SNR \propto \frac{\rho \sin(\alpha)}{\left(\frac{T_1}{T_2}+1\right)-\cos(\alpha)\left(\frac{T_1}{T_2}-1\right)}$$

as given in (1) and, hence, the excitation flip angle (α) giving the highest SNR is determined solely by T1 and T2: $\cos(\alpha_{opt}) = \frac{T_1 - T_2}{T_1 + T_2}$ (2). For oxygenated blood the T1/T2 values at 1.5T are approximately 1200 ms/200 ms while T1/T2 for myocardium are 867 ms/57 ms (1). Based on this, the theoretical flip angle giving the largest contrast between blood and myocardium is 54º.
The purpose of the present study was to systematically investigate CNR and SNR dependence on flip angle in cine B-SSFP scanning and was initiated because practical experience seemed to indicate that excitation using larger flip angles than theoretically predicted often resulted in improved SNR and CNR.

Material and methods
Cardiac, short-axis, single slice cine images were obtained in two volunteers. Scans with flip angles varied between 40º and 130º in steps of 10º were performed. The scanner was a 1.5 T Philips NT/Intera scanner with 30 mT/m gradients and a phased-array cardiac coil was used. The sequence was a retrospectively gated B-SSFP sequence with 30 heart phases acquired during breathholding. Other scan parameters were: FOV=160 mm, matrix=256, slice thickness=5 mm, bandwidth=200 kHz, TR=3.9 ms, and TE=1.8 ms. The TFE turbo factor (#k-lines per heart phase) was varied for optimizing the scan time in relation to the SAR level.
An in vitro scan using a polyvinyl alcohol phantom with blood-like relaxation values (T1/T2=1407 ms/157 ms) was also performed. The scan parameters were as above and a flip angle range from 10º to 130º was covered.

Results
For both volunteer scans, the contrast to noise ratio between blood in the left ventricle and the myocardium peaked around a 90º flip angle as opposed to a theoretical value of 54º (Fig 1). The blood SNR/flip angle curve was similar and also showed a maximum around 90º (theoretical value 45º), while the myocardium SNR curve peaked around 50º (theoretical value 29º) (Fig 2).
The SNR/flip angle curve from the phantom experiment peaked around 40º, which is close to the theoretical value of 37º. However, the measured SNR curve varied less with excitation angle than expected from theory.
The scan time varied with flip angle due to SAR constraints. It was constantly 7 sec for flip angles between 40º and 80º but increased up to 15 sec at 130º. A phantom scanning with a fixed scan time showed that the SNR variation with flip angle did not depend on whether the scan time was fixed or was allowed to vary according to the SAR constriction.

Conclusions
The study showed that the most favorable excitation flip angle in B-SSFP cine cardiac imaging regarding CNR was around 90º. This is considerably higher than the theoretically predicted value and the optimum SNR angle found in a phantom study. The discrepancy might be due to flow effect, but this is not clear at the moment. The increased CNR would, in particular, be advantageous for cardiac function analysis using automatic segmentation. However, visual inspection indicated a slightly increased burden of flow artifacts for flip angle higher than 80º, in particular at early diastole. As the scan time also increases at flip angles higher than 80º due to SAR constraints, the angle should usually be kept below 80º.

References
1) Schär M et al. MRM 51:799 (2004).
2) Herzka DA et al. Proc. of ISMRM 2003, 980.

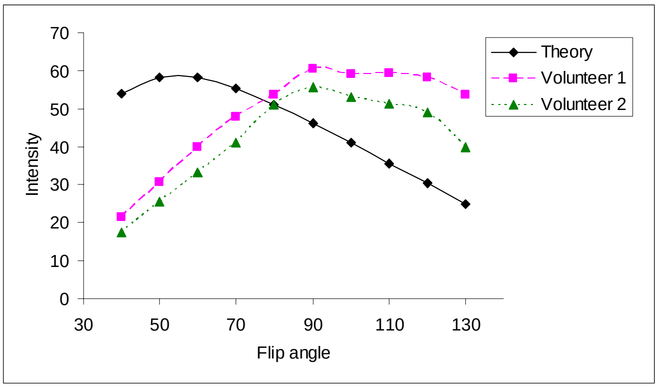

Figure 1. CNR as function of flip angle assessed from volunteer scans and calculated from theory

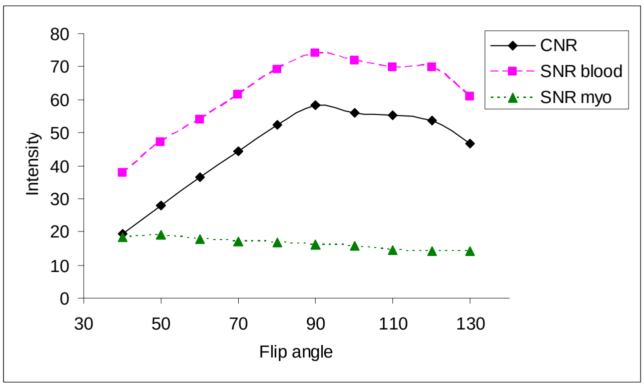

Figure 2. SNR and CNR in volunteer scans