Variable Flip Angle Steady State Free Precession Imaging for Reduction of SAR

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Introduction

Steady state free precession (SSFP) imaging is used in widespread applications such as breath-hold MRI examinations of the abdomen and cardiac due to its very high signal-sampling efficiency and good tissue contrast. SSFP imaging at a high static field strength of 3 T and greater often suffers from specific absorption rate (SAR) problems because a high flip angle and short repetition times are required to obtain an excellent signal-to-noise ratio (SNR) and to reduce banding artifacts, which lead to higher RF power in a short duration.

To overcome these problems, variable flip angle (VFA) schemes were introduced in SSFP imaging [1, 2]. Previous studies have shown that VFA reduces the SAR efficiently because RF-power deposition is proportional to the square of the flip angle. Although these studies have considered the influence of VFA on SNR and spatial resolution, they have not yet discussed the influence on image contrast well. Moreover, they have not shown how the VFA scheme can be applied to cardiac- or breath-gated SSFP imaging.

In the present work, two VFA schemes are proposed to reduce the SAR while maintaining the SNR and image contrast for both gated and non-gated SSFP imaging. We examined the SNR and contrast of healthy volunteer images by comparing the proposed VFA schemes to constant flip angle schemes. The results show that the proposed schemes reduced the SAR by 30% while maintaining the SNR and image contrast.

Method

The main idea of the technique is to use a high flip angle for echoes around the center of a k-space matrix and at times prior to when the echo for the center was obtained. In SSFP imaging, flip angles for around a k-space center are known to mainly affect the SNR and image contrast. In addition, flip angles used to generate echo prior to that of the k-space center also affects the image contrast.

High flip angles are used for conventional non-gated SSFP imaging using a linear-order encoding step until the echo of the k-space center is obtained to maintain SNR and image contrast compared with a constant flip angle. The flip angle and phase encoding (ky) for non-gated SSFP imaging is shown in Figure 1. In this case, a high flip angle (60°) is used until an echo is obtained at the k-space center, and then, gradually the flip angle is decreased as a sine function. Here, flip angles are calculated such that the total RF power was reduced by 30% with regard to a constant flip angle (60°).

By contrast, in the case of gated SSFP imaging, it is necessary to set the flip angle along with a divided k-space called a segment because the order of the measurement timing of echoes vary depending on the segment. The variable flip angle and ky for gated SSFP imaging is shown in Figure 2. In this figure, the upper numbers represent the order of the measurement timing of echoes. A high flip angle (60°) was used in the segment, which included the k-space center, and a low flip angle (less than 60°) was used in other segments since the above concept also applies to this case. In this case, flip angles were set smoothly over the k-space to avoid artifacts. Moreover, flip angles of preparation pulses exposed during waiting times between the segments also varied along with the segments, and flip angles were calculated such that the total RF power was reduced by 30% with regard to a constant flip angle (60°).

The proposed VFA and constant flip angle scheme were applied to SSFP imaging of healthy volunteers, obtaining images from abdominal and cardiac cine MRI studies. We examined the SNR and contrast of images by comparing a VFA scheme to a constant-flip-angle scheme. The measurements were performed on a 1.5 T system (ECHELON Vega®, Hitachi Medical Corporation, Japan). An 8-ch phased-array torso coil was used. Scan parameters of abdominal image are as follows: TR/TE = 4/2 ms, FOV = 350 mm, Matrix size = 144 × 192. Scan parameters of cardiac image are as follows: TR/TE = 4/2 ms, FOV = 350 mm, Matrix size = 176 × 132, number of phases = 22, number of segments = 11

Results and Discussion

As shown in Figure 3, the abdominal and cardiac cine MRI images (one of 22 images) obtained using (a) a constant flip angle (60°), (b) proposed VFA, and (c) a constant flip angle (50°) of which the SAR is the same as (b). The SNR and the CNR obtained under different flip angles are listed in Table 1. The SNR was measured for the blood of the abdominal and cardiac images. The CNR was measured for the blood and the liver in the abdominal image and for the blood and cardiac muscle in the cardiac image. The images demonstrate that variable flip angle does not cause visible blurring. By comparison between (a) and (b), the SNR and CNR are almost the same, even though the SAR of (a) is higher than that of (b). By comparison between (b) and (c), the SNR and the CNR of (b) are higher than that of (c), even though the SARs are the same. Thus, we found that the proposed method reduced the SAR by 30% while maintaining SNR and image contrast.

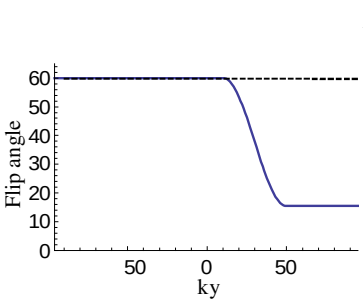

Figure 1. Variable flip angle for non-gated imaging

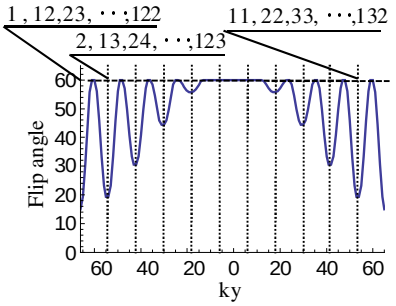

Figure 2. Variable flip angle for gated imaging

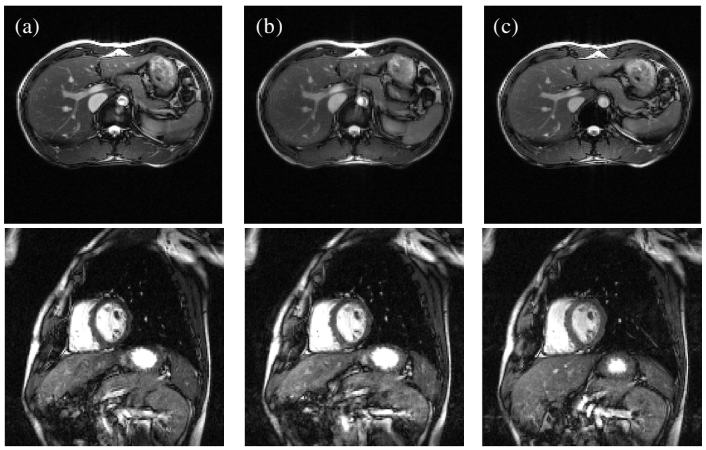

Figure 3. Images obtained using (a) a constant flip angle (60˚), (b) proposed VFA, (c) a constant flip angle (50˚) with same SAR as (b).

Conclusion

We have described VFA schemes for non-gated and gated imaging to reduce the SAR in SSFP imaging. We found that the proposed schemes reduced the SAR by 30% while maintaining SNR and image contrast. The variable flip angle scheme provides a useful tool to reduce SAR in a high static field strength MRI system.

References

[1] Schäffter T., et al., ISMRM, **11**, p2662, 2004.
[2] Paul D., et al., ISMRM, **15**, p1650, 2007.

Table 1. Several SNR and CNR

	(a) Constant FA (60°)	(b) VFA	(c) Constant FA (50°)
Abdominal SNR	95	92	84
Abdominal CNR	62	46	59
Cardiac SNR	126	124	93
Cardiac CNR	86	81	50