Cardiac Cine MRI at 3.0 Tesla: Comparison of Image Quality between SSFP and FLASH Sequence

Jumpei Suyama\textsuperscript{1}, Noritaka Seino\textsuperscript{3}, Makoto Saiki\textsuperscript{1}, Yoshimitsu Ohgiya\textsuperscript{1}, Masanori Hirose\textsuperscript{1}, Kyouichi Kaneko\textsuperscript{2}, Yusuke Kodama\textsuperscript{2}, Yasushi Akutsu\textsuperscript{2} and Takehiko Gokan\textsuperscript{1}

Abstract: This study compared steady-state free precession (SSFP) with Fast Low Angle Shot (FLASH) at 3.0 T cardiac Cine MRI with respect to contrast to noise ratio (CNR) and visual image quality assessment. All images were acquired on a 3.0-T Siemens MAGNETOM trio. Seven healthy volunteers (all males, mean age 32.5±7 years) underwent magnetic resonance imaging using SSFP and FLASH sequence on the same day. For both SSFP and FLASH imaging, 8-mm thick short axis and long axis views were acquired with equal matrix size (192×192). CNR calculations were performed on the short axis images acquired at end systole time points. Three radiologists independently assessed image quality. SSFP images were superior to FLASH images with respect to CNR (SSFP: 7.14±2.16, FLASH: 3.57±1.83, \( P < 0.001 \)). In image quality, SSFP images were superior to FLASH in both short and long axis views (\( P < 0.01 \)). Although SSFP images contained dark blood artifacts in 3 cases, these images were improved by frequency offset. SSFP sequences provided higher quality images than FLASH sequences, and would be available for cardiac cine MRI at 3.0 T.

Key words: cardiac cine MRI, 3.0 Tesla, SSFP, FLASH

Introduction

The clinical use of cardiac magnetic resonance imaging (MRI) has increased in recent years, especially for whole-heart coronary MR angiography and the identification of myocardial ischemia by perfusion study. The functional cardiac exam is a fundamental method for many cardiac MRI investigations. This exam can be performed using either the steady-state free precession (SSFP) or fast low angle shot (FLASH) method.

The FLASH technique-based gradient echo sequence was introduced in 1986\textsuperscript{1). The features of this sequence are RF pulse with low flip angle, short repetition time (2-20 msec)\textsuperscript{2), and a spoiler pulse that can reduce the effect of residual transverse magnetization. The SSFP sequence is also a gradient echo sequence with low flip angle and short
repetition time, but includes both transverse and longitudinal magnetization without a spoiler pulse\textsuperscript{4}. At 1.5 tesla (T), cine MRI with SSFP sequence defines the current standard, because the sequence can provide higher image quality than the previously used FLASH sequence\textsuperscript{5-7}. At 3.0 T, the higher field strength enables a higher signal to noise ratio (SNR) and contrast to noise ratio (CNR). However, the SSFP sequence is more limited by the specific absorption rate (SAR) or specific artifact, and SAR increases with field strength. The first solution to this problem is to decrease the flip angle, but this worsens contrast\textsuperscript{8-10}. At 3.0 T cine MRI, SSFP is reportedly slightly superior to FLASH sequence in terms of CNR and visual image quality assessment\textsuperscript{11}, but 3.0 T MRI has been improved in terms of susceptibility or sequence optimization since that study.

This study compared SSFP and FLASH sequence images with respect to CNR, the presence of artifacts and visual image quality at 3.0 T MRI.

**Materials and Methods**

Seven volunteers (mean age 32.5±7.1 years, age range 25–42 years, all males) without any known history of diabetes, hypertension, renal failure, or cardiac disease were enrolled in this study. All examinations were performed using a 3.0-T MRI system (MAGNETOME Trio A Tim System; Siemens Medical Solutions, Erlangen, Germany) with a 6-ch balance coil and 6-ch spinal balance coil. The parameters for the SSFP sequence were as follows: field of view (FOV) = 360 mm, matrix 192×192, 8-mm slice thickness, TR 42, TE 1.2 1 flip angle 42°, IPAD). The parameters for the FLASH sequence were as for SSFP except for TR 39.24, TE 2.4, and flip angle 12°.

**CNR**

The signal intensities (SI) of the septal myocardium (m) and ventricle (v) were measured at the end of systole, which is considered to produce fewer errors. The SI of the septal myocardium and ventricle was defined as the mean signal from a semi-circular ROI of 50–150 mm\textsuperscript{2}. The SI of the background was defined as the mean signal from a semi-circular ROI of 200 mm\textsuperscript{2} in the same slice as the m and v were measured, and standard deviation (SD) was calculated: SD was defined as five times the mean value of the SI in background. CNR was calculated as: $\text{CNR} = \frac{(\text{SI}_m - \text{SI}_v)}{\text{SD}}$\textsuperscript{12}.

**Grading**

The evaluation objects were artifacts and visual image contrast. Imaging assessment demonstrated that both FLASH and SSFP yielded images that could be analyzed at both field strengths. We used a scoring system to assess image quality as described previously\textsuperscript{11}:

$\quad 4 = \text{Perfect image of left ventricle (LV) and right ventricle (RV), no significant artifacts in these regions, blood pool well defined.}$

$\quad 3 = \text{Perfect image of LV, no artifacts in this region, blood pool well defined, RV can be}$
measured despite some artifacts.

2 = LV and RV can be measured despite some artifacts.
1 = LV and RV can be measured despite some artifacts, RV cannot be measured with any degree of confidence.
0 = LV and RV cannot be measured with any degree of confidence.

Three radiologists assessed image quality in a blinded fashion.
Values of CNR and the image assessment were compared using a bi-directional paired Student’s t-test.

Results

Fig. 1 shows a typical short axis acquisition of a volunteer using both SSFP and FLASH. An overview of all CNR numbers can be found in Fig. 5. In all cases, the SSFP sequence showed a higher score than the FLASH sequence, and the average score of SSFP (7.14 ± 2.16) was also higher than the FLASH sequence (3.57±1.83; P < 0.001). The average score of SSFP sequence (long axis 2.86 ± 0.64, short axis 3.14±0.35) was higher than the FLASH sequence (long axis 1.28 ± 0.45; P < 0.01, short axis 2.33±0.53; P < 0.01). In the SSFP, the most frequent score was 3 on both short and long axis views. With the FLASH sequence it was 1 on long axis and 2 on short axis. Using the SSFP sequence, off-resonance artifacts occurred in three cases, and shifting the resonance offset corrected the artifact in two cases (Fig. 2). However, in the remaining case, a severe artifact was present that could not be corrected by shifting the offset frequency (Fig. 3). In the FLASH sequence, 5 cases showed flow artifact into the left ventricle (Fig. 4).
Table 1. Assessment of short and long axial stacks.

<table>
<thead>
<tr>
<th></th>
<th>4</th>
<th>3</th>
<th>2</th>
<th>1</th>
<th>0</th>
<th>average score</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSFP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.86 ± 0.64</td>
</tr>
<tr>
<td>long axis</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>short axis</td>
<td>1</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3.14 ± 0.35</td>
</tr>
<tr>
<td>FLASH</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.28 ± 0.45</td>
</tr>
<tr>
<td>long axis</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>short axis</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>0</td>
<td>2.33 ± 0.53</td>
</tr>
</tbody>
</table>

Fig. 2. (a) Short-axis SSFP images at end diastole, showing dark band artifacts (arrow). (b) By resonance offset, the artifacts were reduced.

Fig. 3. (a) Short-axis SSFP images at end-diastole, showing dark band artifacts (arrow). (b) By resonance offset, the artifact was shifted to another site (arrow), and could no longer be seen.
The aim of this study was to compare cardiac cine MRI with SSFP and FLASH sequences at 3.0 T in healthy volunteers. Some studies found that cardiac cine MRI examination at 1.5 T by SSFP sequence was feasible, but at 3.0 T, MRI SSFP sequences were thought to be limited by the higher level of artifacts, which were attributed to off-resonance effects and
increased susceptibility$^{8,13,14}$.

Tyler et al$^{11}$ evaluated image quality by FLASH and SSFP sequence at 1.5 and 3.0 T, and they used the scoring system of the present study. In their study, the best images were by SSFP at 1.5 T, followed by SSFP at 3.0 T. The average scores were 3.8 and 2.7. In the 3.0-T SSFP sequence, CNR was improved although it suffered from increased artifacts that did not prevent analysis, but did not aid image interpretation. For the FLASH sequence, the 3.0-T acquisition was better than the 1.5-T acquisition with average scores of 2.6 and 2.1. At 3.0 T, the image scores did not differ significantly between SSFP and FLASH sequences (2.7 vs. 2.6), while at 1.5 T, the SSFP sequence images were superior to those at 3.0 T because of the associated artifacts. At 3.0 T, both SSFP and FLASH sequence images showed improved SNR and CNR.

Our study results differed from the study of Tyler et al$^{7}$ at 3.0 T in that the SSFP sequence images were obviously superior to the FLASH sequence, although the cause of difference was unclear. In our study, most cases showed flow artifacts in the FLASH sequences, while SSFP sequence images revealed artifact in only one case. The frequency of artifact was thought to be the major factor in the differentiation. At 3.0 T cardiac MRI, SAR limitations and various artifacts limited the flip angle and RF pulse$^{8}$, while in the FLASH sequence, image parameters were suitable with reference to Tyler’s study. For the SSFP sequence it was possible to use parallel imaging or to prolong the RF pulse and echo time, while improved shimming, RF pulses, and shorter TR will help to remove residual problems$^{9-11}$. One limitation of this study was that the examination was performed using only seven volunteers, and older or obese people were not included. The differences in the case groups compared to the previous report were also considered to be another cause of result differentiation. Another limitation is that it has been examined in a single institution and with a single MRI scanner. It seems that further study is needed to include a wider disease case group and/or many institutions.

**Conclusion**

This study indicated that cardiac imaging at 3.0 T with the SSFP sequence was more feasible than the FLASH sequence, although one case showed strong artifacts. SSFP sequence imaging seemed suitable at 3.0-T cardiac cine MRI and at 1.5-T MRI.

**References**


[Received June 17, 2009: Accepted August 15, 2009]