Comparison of SPAMM and SENC Methods for Evaluating Peak Circumferential Strain at 3T

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(Received August 1, 2012; Accepted October 31, 2012; published online March 11, 2013)

We compared peak circumferential strain (Ecc) values with spatial modulation of magnetization (SPAMM) and strain-encoded (SENC) magnetic resonance (MR) imaging at 3 tesla. Correlation coefficients of the averaged peak Ecc values of the 2 methods were statistically significant. However, the average peak Ecc value was significantly lower with SPAMM (-13.5% ± 3.3%) than with SENC (-21.6% ± 3.4%) (P < 0.0001). The SENC method showed higher circumferential strain than the SPAMM method at 3T.

Keywords: magnetic resonance imaging, myocardial strain, peak circumferential strain, spatial modulation of magnetization, strain-encoded

Introduction

Regional myocardial function is one of the most important indicators of myocardial assessment.¹ With magnetic resonance (MR) imaging, conventional tagging using spatial modulation of magnetization (SPAMM) can be used to assess regional myocardial contractility;² the method uses special saturation pulses that create saturated in-plane magnetization tags as a stripe or grid. The tagged myocardium deforms with myocardial contraction and expansion. The strain-encoded (SENC) method³ applies through-plane tags that can be narrower than with the SPAMM method. Comparisons between the SPAMM and SENC methods have been reported at 1.5 tesla⁴–⁶ but not at 3T.

In general, the persistence of tags depends on the longitudinal relaxation time of the labeled tissue. Therefore, a static magnetic field strength of 3T should have the advantage of prolonged tag persistence compared to 1.5T. However, the higher static magnetic field strength induces larger artifacts due to B₀/B₁ inhomogeneity and susceptibility effects. We compared left ventricular myocardial peak circumferential strain with the SENC and SPAMM methods at 3T.

Materials and Methods

We retrospectively evaluated 66 consecutive patients who underwent cardiac MR imaging with the SPAMM and SENC methods and delayed enhancement between July 2009 and March 2011. We excluded 40 patients with late gadolinium enhancement (LGE) because of the inhomogeneous nature of the myocardium.⁷ We used a different analysis software package for each method. We focused on differences in the 2 different methods without errors due to regional inhomogeneity. Twenty-six patients with no LGE of the left ventricle were included in the analysis. Table 1 details patient characteristics. Images were obtained with a 3T whole-body scanner (AchievaTX; Philips Medical Systems, Best, The Netherlands) using a 32-channel phased-array receiver torso-cardiac coil. Electrocardiography...
Table 1. Patient characteristics (n = 26)

| Characteristics (n = 26) | Value |
|-------------------------|-------|
| Age (mean ± SD)         | 55.8 ± 16.4 |
| Sex                     | Male = 18, Female = 8 |
| LVEF (%)                | 55.7 ± 16.1 |
| Heart rate (beats/min)  | 63.5 ± 9.5 |

| Disease                  | Value |
|--------------------------|-------|
| cardiac sarcoidosis      | 6     |
| arrhythmia               | 5     |
| hypertrophic cardiomyopathy | 3     |
| dilated cardiomyopathy   | 3     |
| aortic regurgitation     | 3     |
| heart failure            | 3     |
| pulmonary hypertension   | 2     |
| diabetes mellitus        | 1     |

SD: standard deviation
LVEF: left ventricular ejection fraction

(ECG) was used in all studies for R-wave triggering. SPAMM measurements were performed with a short-axis (SA) viewing plane at the apical, midventricular, and basal left ventricular myocardium. SENC measurements were performed with a 4-chamber (4-CH) viewing plane to assess left ventricular circumferential strain in the same locations as with SPAMM.

**Imaging Protocol**

**SPAMM acquisition and implementation**

Imaging parameters for SPAMM were repetition time (TR), 4.5 ms; echo time (TE), 2.5 ms; number of signal averages (NSA), one; 8-mm slice thickness; 8-mm tag grid-type spacing (in-plane); 10° flip angle; 144 matrix; and 360-mm field of view (FOV) with acquisition time of 14.0 s. Acquisitions were performed with an SA viewing plane at the apical, midventricular, and basal left ventricular myocardium with ECG-triggered breath holding.

The peak circumferential strain (Ecc) at the septum and lateral wall at each left ventricular level was measured with the SPAMM method using dedicated SPAMM software automated image pattern tracking on a Ziosation 2 (Ziosoft, Tokyo, Japan).

**SENC acquisition and implementation**

Imaging parameters for SENC were TR, 15 ms; TE, 0.76 ms; NSA, one; 10-mm slice thickness; 2.5-mm tag spacing (through-plane); 30° flip angle; 108 matrix; and 320-mm FOV with acquisition time of 8.0 s. The acquisitions were performed at the 4-CH viewing plane with ECG-triggered breath holding.

We measured peak Ecc with the SENC method using dedicated Diagnosoft SENC version 2.05 software (Diagnosoft Inc., Palo Alto, CA, USA). SENC acquisition generates low-tuning and high-tuning images that are created with differently tuned gradients in the slice selection direction. Two images are combined, and strain is calculated. Figure 1 shows the strain curves obtained using each method.

**Data and statistical analysis**

Peak circumferential strain was obtained at the left ventricular septum and lateral wall at the apical, midventricular, and basal left ventricular levels. A total of 6 segmental points were measured with dedicated software (Fig. 2). Data were presented as mean ± standard deviation. We performed Pearson’s correlation analysis to determine correlation coefficients between the 2 methods and used paired t-test to compare peak Ecc values between SPAMM and SENC, with a significance level of 5% (P < 0.05). Bland-Altman plots were also made. We used Steel-Dwass test with Bonferroni correction to compare peak Ecc values between the 2 methods for the different ventricular levels. All statistical analyses were performed with JMP software (version 10; SAS Institute Inc., Cary, NC, USA). Data were obtained from the following processes.

**Patient-based analysis:** To compare the SPAMM and SENC methods, we calculated the averaged peak Ecc value of all points and the correlation coefficient between SPAMM and SENC.

**Segment-based analysis:** We calculated the mean peak Ecc value for each ventricular level, comparing a total of 3 peak Ecc values for each level between SPAMM and SENC; compared regional peak Ecc values for each of the 6 segments between SPAMM and SENC; and compared the mean Ecc values between the different left ventricular levels for each method.

**Results**

**Patient-based analysis:** The averaged peak Ecc values from 156 points acquired from 26 patients were −13.5% ± 3.3% with SPAMM and −21.6% ± 3.4% with SENC. The correlation coefficient between SPAMM and SENC was sufficient (r = 0.558) and statistically significant (P = 0.003) (Fig. 3). The averaged peak Ecc value was significantly higher obtained with SENC than with SPAMM (P < 0.0001).

**Segment-based analysis:** (1) The mean peak
Ecc values at each ventricular level were $-11.0\% \pm 6.4\%$ (SPAMM) and $-22.8\% \pm 5.8\%$ (SENC) for the apical left ventricular level, $-16.0\% \pm 6.0\%$ (SPAMM) and $-21.5\% \pm 5.3\%$ (SENC) for the midventricular level, and $-13.5\% \pm 6.8\%$ (SPAMM) and $-20.4\% \pm 5.3\%$ (SENC) for the basal level (Table 2). The mean peak Ecc value at each level was higher for SENC than SPAMM ($P<0.05$ for all). There were moderate correlations between SPAMM and SENC at each left ventricular level ($r=0.339$, apical; $r=0.457$, midventricular; $r=0.316$, basal left ventricular) ($P<0.05$ for all).

(2) The peak Ecc values were significantly higher at all segments with SENC than with SPAMM ($P<0.05$). Table 3 shows the correlation coefficient between SPAMM and SENC for the regional peak Ecc values for 6 segments. For comparison of the correlation coefficients, there were significant correlations of the peak Ecc values between SPAMM
Table 2. Comparison of peak circumferential strain (Ecc) values between the spatial modulation of magnetization (SPAMM) and strain-encoded (SENC) methods at each ventricular level

| Ventricular levels | peak Ecc [%] | r       | P            |
|-------------------|--------------|---------|--------------|
|                   | SPAMM        | SENC    |              |
| Apical            | −11.0 ± 6.4  | −22.8 ± 5.8 | 0.339(P = 0.014) | <0.0001 |
| Mid-ventricular    | −16.0 ± 6.0  | −21.5 ± 5.3 | 0.457(P < 0.001) | <0.0001 |
| Basal             | −13.5 ± 6.8  | −20.4 ± 5.3 | 0.316(P = 0.002) | <0.0001 |

Table 3. Comparison of peak circumferential strain (Ecc) values between the spatial modulation of magnetization (SPAMM) and strain-encoded (SENC) methods at each segmental point

| Segmental Points  | peak Ecc [%] | r       | P            |
|-------------------|--------------|---------|--------------|
|                   | SPAMM        | SENC    |              |
| Apical septal     | −10.9 ± 6.3  | −21.6 ± 6.9 | 0.628(P < 0.001) | <0.0001 |
| Apical lateral    | −11.1 ± 6.7  | −24.1 ± 4.3 | −0.055(P = 0.788) | <0.0001 |
| Mid-ventricular septal | −14.3 ± 5.4  | −19.2 ± 6.0 | 0.367(P = 0.065) | 0.0007  |
| Mid-ventricular lateral | −17.6 ± 6.3  | −23.9 ± 3.1 | 0.507(P = 0.008) | <0.0001 |
| Basal septal      | −13.0 ± 7.0  | −18.4 ± 6.1 | 0.536(P = 0.005) | 0.0002  |
| Basal lateral     | −13.9 ± 6.6  | −22.3 ± 3.5 | −0.064(P = 0.757) | <0.0001 |

Fig. 4. Scatter plots of peak circumferential strain (Ecc) values for each segment with the spatial modulation of magnetization (SPAMM) and strain-encoded (SENC) methods.

...and SENC at the apical septal, mid lateral, and basal septal levels (P < 0.05). On the other hand, there were no significant correlations of regional peak Ecc value at the apical lateral (P = 0.788), mid septal (P = 0.065), and basal lateral wall (P = 0.757) between SPAMM and SENC. Figure 4 shows scatter plots of both methods for each segment. Bland-Altman plots also showed a tendency of higher peak Ecc values with SENC (Fig. 5).

(3) Between different levels, the mean peak Ecc value was higher at the apical ventricular level than basal ventricular level with SENC (Fig. 6). There
were no significant differences between apical and midventricular levels and between midventricular and basal levels. However, the mean peak Ecc value at the apical ventricular level with SPAMM was not significantly higher than basal ventricular level as seen with SENC (Fig. 4).
Discussion

In this study, we compared peak Ecc values between the SPAMM and SENC methods at 3T and found higher average peak Ecc values with SENC than SPAMM, higher mean peak Ecc value with SENC than SPAMM at all ventricular levels, and higher regional peak Ecc values with SENC than SPAMM at all segments. There were significant correlations in the apical septal, midlateral, and basal septal segments between the 2 methods. However, there were no significant correlations for the regional peak Ecc values at the apical lateral, midseptal, and basal lateral segments; and the mean peak value at the apical ventricular level with SENC was higher than at the basal ventricular level, but those values with SPAMM showed no such difference.

Neizel and associates\(^4\) demonstrated higher peak Ecc values with SENC than SPAMM at 1.5T, as we did at 3T. The reason for the lower strain values with SPAMM was attributed to the greater capacity of the SENC method than the SPAMM method to evaluate spatial resolution.\(^8\) Moreover, the reason for the lack of significant correlations between peak Ecc values at the apical and basal lateral left ventricular wall with SPAMM and SENC methods might be that the SPAMM method at 3T was more likely to be affected by B\(_1\) inhomogeneity and susceptibility artifacts from around the air in the lung at the left ventricular lateral wall. Motion artifacts, such as blurring and ghosting due to incomplete breath holding, might considerably affect the lower peak Ecc values with SPAMM. Application of the tag to the through-plane direction with the SENC method\(^3\) might have circumvented such artifacts. Hamdan and colleagues\(^9\) noted higher peak Ecc value at the apical ventricular level than the midventricular and basal ventricular levels detected only with the SENC method. In this study, we found inhomogeneity of strain values between different LV levels with SENC but observed no such difference with SPAMM. The SPAMM method might be affected by susceptibility artifacts from air in the lung around the apical ventricular level.

This study has some limitations. First, we could compare the 2 methods in only the circumferential direction because the SPAMM method can evaluate circumferential and radial strain and the SENC method, circumferential and longitudinal strain. Second, we used a different algorithm with different software to evaluate each method. Different algorithms within different softwares might yield different peak Ecc values with each method that affect the evaluation range. The SPAMM method uses segment-based calculations, while SENC uses pixel-based calculations. The average strain value was lower using segment-based than pixel-based analysis. In contrast, the pixel-based evaluation with SENC was useful for differentiating subendocardial and transmural myocardial infarctions.\(^7\) The Compared to SENC, the SPAMM method is limited by tag space and its segment-based analysis. Differences between the 2 methods might be due to the limitations of the SPAMM method.

Conclusion

We evaluated and compared peak Ecc values obtained with the SPAMM and SENC methods at 3T and found significant correlations of strain values between the 2 methods. However, circumferential strain was higher with SENC than SPAMM.

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