Radiology

ORIGINAL RESEARCH ■ CARDIAC IMAGING

Myocardial Late Gadolinium Enhancement: Accuracy of T1 Mapping–based Synthetic Inversion-Recovery Imaging[1]

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Purpose: To compare the accuracy of detection and quantification of myocardial late gadolinium enhancement (LGE) with a synthetic inversion-recovery (IR) approach with that of conventional IR techniques.

Materials and Methods: This prospective study was approved by the institutional review board and compliant with HIPAA. All patients gave written informed consent. Between June and November 2014, 43 patients (25 men; mean age, 54 years ± 16) suspected of having previous myocardial infarction underwent magnetic resonance (MR) imaging, including contrast material–enhanced LGE imaging and T1 mapping. Synthetic magnitude and phase-sensitive IR images were generated on the basis of T1 maps. Images were assessed by two readers. Differences in the per-patient and per-segment LGE detection rates between the synthetic and conventional techniques were analyzed with the McNemar test, and the accuracy of LGE quantification was calculated with the paired *t* test and Bland-Altman statistics. Interreader agreement for the detection and quantification of LGE was analyzed with κ and Bland-Altman statistics, respectively.

Results: Seventeen of the 43 patients (39%) had LGE patterns consistent with myocardial infarction. The sensitivity and specificity of synthetic magnitude and phase-sensitive IR techniques in the detection of LGE were 90% and 95%, respectively, with patient-based analysis and 94% and 99%, respectively, with segment-based analysis. The area of LGE measured with synthetic IR techniques showed excellent agreement with that of conventional techniques (4.35 cm^2 ± 1.88 and 4.14 cm^2 ± 1.62 for synthetic magnitude and phase-sensitive IR, respectively, compared with 4.25 cm^2 ± 1.92 and 4.22 cm^2 ± 1.86 for conventional magnitude and phase-sensitive IR, respectively; $P > .05$). Interreader agreement was excellent for the detection ($\kappa > 0.81$) and quantification (bias range, −0.34 to 0.40; $P > .05$) of LGE.

Conclusion: The accuracy of the T1 map–based synthetic IR approach in the detection and quantification of myocardial LGE in patients with previous myocardial infarction was similar to that of conventional IR techniques. The use of T1 mapping to derive synthetic LGE images may reduce imaging times and operator dependence in future T1 mapping protocols with full left ventricular coverage.

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Myocardial viability assessment with contrast material–enhanced magnetic resonance (MR) imaging relies on the detection of late gadolinium enhancement (LGE) in the myocardium (1). Two major inversion-recovery (IR) MR imaging approaches have been developed for the evaluation of LGE: magnitude-reconstructed and phase-sensitive IR imaging (2). Because the evaluation of magnitude-reconstructed images requires the successful nulling of the signal intensity in the normal myocardium, the image quality is highly dependent on the inversion time (TI) used for the acquisition (3). Phase-sensitive IR sequences have partially overcome this drawback by providing appropriate myocardial contrast and enabling accurate quantification of LGE independently from the TI used (2,4). However, to our knowledge, magnitude-reconstructed imaging is still the most common approach used in clinical practice.

Recent technologic developments in modified Look-Locker IR (MOLLI)–based T1 mapping (5–7) allow not only fast and reliable pixel-wise T1 mapping of the heart but also the calculation of a new generation of IR images referred to as synthetic IR images (5–7). This T1-based synthetic IR imaging technology was originally developed in a MOLLI prototype to support image coregistration in the implementation of a motion correction algorithm (5,7). Synthetic IR images can be retrospectively calculated at any theoretic TI on the basis of the voxel-by-voxel T1 dataset acquired with a prototype MOLLI sequence (5).

We performed this study to prospectively compare the accuracy of detection and quantification of myocardial LGE with a synthetic IR approach with that of conventional magnitude and phase-sensitive IR techniques.

Advances in Knowledge

- Synthetic inversion-recovery (IR) cardiac MR images can be retrospectively derived from T1 maps at any theoretic inversion time (TI).
- Synthetic IR MR imaging has high per-patient and per-segment sensitivity (90% and 94%, respectively) and specificity (96% and 99%, respectively) in the detection of myocardial late gadolinium enhancement (LGE) in patients with myocardial infarction.
- In patients with myocardial infarction, synthetic IR techniques provide similar quantification accuracy (infarct fraction, 18.10% and 17.23% for magnitude and phase-sensitive IR imaging, respectively) to conventional IR techniques (infarct fraction, 17.81% and 17.71% for conventional magnitude and phase-sensitive IR imaging, respectively; not significant) in a single myocardial section.

Materials and Methods

B.S.S. is an employee of Siemens Healthcare. U.J.S. receives research support from Bayer, Bracco, GE Healthcare, Medrad, and Siemens Healthcare. The other authors had control of the data and the information submitted for publication.

Patient Selection

Our institutional review board approved our study protocol, and written informed consent was obtained from each patient before enrollment in the study. The study complied with the Health Insurance Portability and Accountability Act. Between June and November 2014, 43 consecutive patients were prospectively enrolled at our institution. Inclusion criteria were *(a)* age range of 18–90 years and *(b)* referral for clinically indicated MR imaging for viability assessment in known or suspected myocardial infarction. General MR imaging exclusion criteria were applied. Patient demographics and medical history were obtained from a medical records chart review (A.V.S., with 7 years of experience in cardiac MR imaging).

Implications for Patient Care

- The generation of synthetic IR MR images does not require additional imaging time, which may eliminate the need for conventional LGE imaging once T1 mapping is integrated into clinical routine.
- Synthetic IR techniques allow for the retrospective review of the entire TI range and the selection of the most optimal TI, which would eliminate the need for technologists to optimize the LGE acquisition (eg, by obtaining a scout view before LGE imaging and readjusting the TI owing to the time elapsed) and may reduce variability in image quality.

Cardiac MR Imaging Protocol

All patients underwent MR imaging with a 1.5-T unit (Magnetom Avanto; Siemens Healthcare, Erlangen, Germany) by using phased-array radiofrequency coils with six body elements positioned anteriorly and six spine elements positioned posteriorly. Imaging was performed during breath hold at end-expiration. The imaging protocol included scout and cine acquisitions and contrast material–enhanced (0.1 mmol/kg gadobenate dimeglumine [MultiHance, Bracco, Princeton, NJ]) LGE and MOLLI-based T1 acquisitions. For the purpose of our study, only LGE images and T1 maps were evaluated.

Conventional LGE imaging.—LGE imaging was part of the standard

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Abbreviations:
IR = inversion recovery
LGE = late gadolinium enhancement
MOLLI = modified Look-Locker IR
TI = inversion time

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Guarantors of integrity of entire study, A.V.S., U.J.S.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; manuscript final version approval, all authors; agrees to ensure any questions related to the work are appropriately resolved, all authors; literature research, A.V.S., B.R., C.N.D.C., G.M., P.M.C., R.V., U.J.S.; clinical studies, A.V.S., P.S., C.N.D.C., G.M., P.M.C., U.J.S.; statistical analysis, A.V.S., C.N.D.C., R.V.; and manuscript editing, all authors

Conflicts of interest are listed at the end of this article.

clinical protocol and considered the standard of reference in our study. Electrocardiographically gated short-axis IR images covering the entire left ventricle were generated 10–15 minutes after the intravenous administration of a gadolinium-based contrast material by using a single-shot gradient-echo pulse sequence with the following typical parameters: field of view, 340 × 255 mm^2; section thickness, 8 mm; image acquisition matrix, 192 × 106; reconstruction matrix, 192 × 144; in-plane spatial resolution, 1.77 × 1.77 mm^2; repetition time msec/echo time msec, 2.6/1.1; bandwidth, 965 Hz/pixel; and flip angle, 50°. Parallel imaging was used with an acceleration factor of 2, and Cartesian readout was applied. Single-shot imaging was chosen over segmented high-spatial-resolution IR acquisition because it provides comparable spatial resolution to that of T1 mapping. The acquisition time was less than 15 seconds, depending on the heart rate and the number of short-axis sections covering the left ventricle. The acquired single-shot images were immediately reviewed by a radiologist (P.S., with 13 years of experience in cardiac MR imaging), a single short-axis section was selected, and the section position and orientation were copied to the T1 mapping acquisition. In the presence of LGE, a short-axis section covering the area of LGE was selected; otherwise a midventricular section was imaged. When LGE was present, a section that contained both infarcted and normal myocardium was chosen to allow the measurement of the signal intensity of the normal myocardium. The delay between single-shot LGE imaging and T1 mapping was approximately 1 minute, but always less than 2 minutes.

T1 mapping.—T1 mapping was performed immediately after conventional LGE imaging. Section position and orientation of one short-axis view (involving the area of LGE if visible on magnitude-reconstructed or phase-sensitive IR images) was inherited from the conventional LGE acquisition. An investigational prototype MOLLI-based T1-mapping sequence (WIP448B, Siemens) was used to acquire a pixel-wise T1 map of the myocardium, incorporating inline respiratory motion correction (7), phase-sensitive fitting, and a protocol optimized according to Xue et al (8). With this modified protocol, a series of nine images with nine different TIs within 11 heartbeats is acquired. Single-shot steady-state free-precession readout was applied to generate the images. Acquisition was performed by using the following typical parameters: field of view, 300 × 256 mm^2; section thickness, 8 mm; image acquisition matrix, 192 × 128; reconstruction matrix, 192 × 164; in-plane spatial resolution, 1.56 × 1.56 mm^2; 2.6/1.1; bandwidth, 1085 Hz/pixel; flip angle, 35°; and parallel imaging acceleration factor, 2. An adiabatic inversion pulse was used to improve inversion efficiency (6). The TI for the first inversion was set at 110 msec, with 80-msec increments for the second and third inversions, resulting in initial TIs of 190 and 270 msec, respectively. T1 maps were generated on the imaging unit by using three-parameter least-squares curve fitting, a Look-Locker correction, and an additional correction factor to account for imperfect inversion (6).

Image Analysis

Image assessment was performed by two independent readers (A.V.S. and B.R.). Each of the readers performed both the qualitative and quantitative analyses independently of each other. The readers first evaluated all magnitude-reconstructed and phase-sensitive IR image series in a random order. After a hiatus of at least 7 days to minimize recall, the readers performed the assessment of the synthetic magnitude-reconstructed and phase-sensitive IR images in a random order. In case of disagreement, a third, expert reader (P.S.) arbitrated.

Synthetic IR image generation.—T1 maps were imported to an in-house developed analytic application integrated in the noncommercially available Research Mass Software (Leiden University Medical Center, Leiden, the Netherlands). This application can compute synthetic IR images at any theoretical TI by using the following equations:

$$\mathrm{SI}\ (\mathrm{TI})_{\mathrm{PSIR}} = 1\text{–}2 \times \exp\ (-\mathrm{TI}/\mathrm{T1}) \quad (1)$$

and

$$\mathrm{SI}\ (\mathrm{TI})_{\mathrm{MagIR}} = |\mathrm{SI}\ (\mathrm{TI})_{\mathrm{PSIR}}|, \quad (2)$$

where MagIR is magnitude-reconstructed IR, PSIR is phase-sensitive IR, and SI is signal intensity. Equation (1) keeps the signal polarity and is used to compute phase-sensitive signal intensity, whereas Equation (2) calculates the absolute value of magnetization and is used to compute magnitude signal intensity. SI (TI) is the signal intensity at a given TI.

The application was set up to generate 21 synthetic magnitude-reconstructed and phase-sensitive IR images between TIs of 200 and 400 msec at 10-msec increments. From these image pools, the images with the exact same TI as used for conventional imaging were selected (Fig 1).

Qualitative LGE evaluation.—Images were imported in the Research Mass Software. Endo- and epicardial contours of the left ventricle were traced manually. A reference point was placed in the inferior interventricular sulcus, and the myocardium was divided into six (in the basal and midventricular thirds) or four (in the apical third) segments according to the American Heart Association's 17-segment model (9). LGE was defined as a circumscribed area of elevated signal intensity (relative to the remainder of the myocardium) within the left ventricle wall.

Quantitative LGE evaluation.—To evaluate the area of LGE, the mean signal intensity in the normal myocardium was measured by using a region of interest drawn in an area of normal myocardium containing at least 100 pixels. A binary threshold algorithm that uses 5 standard deviations above the average signal intensity of the normal myocardium was applied to delineate the area showing LGE (10,11). Pixels above this threshold limit were considered to be part of the infarcted area. Infarct pixels were automatically counted by the software, and the total area of these pixels

Figure 1

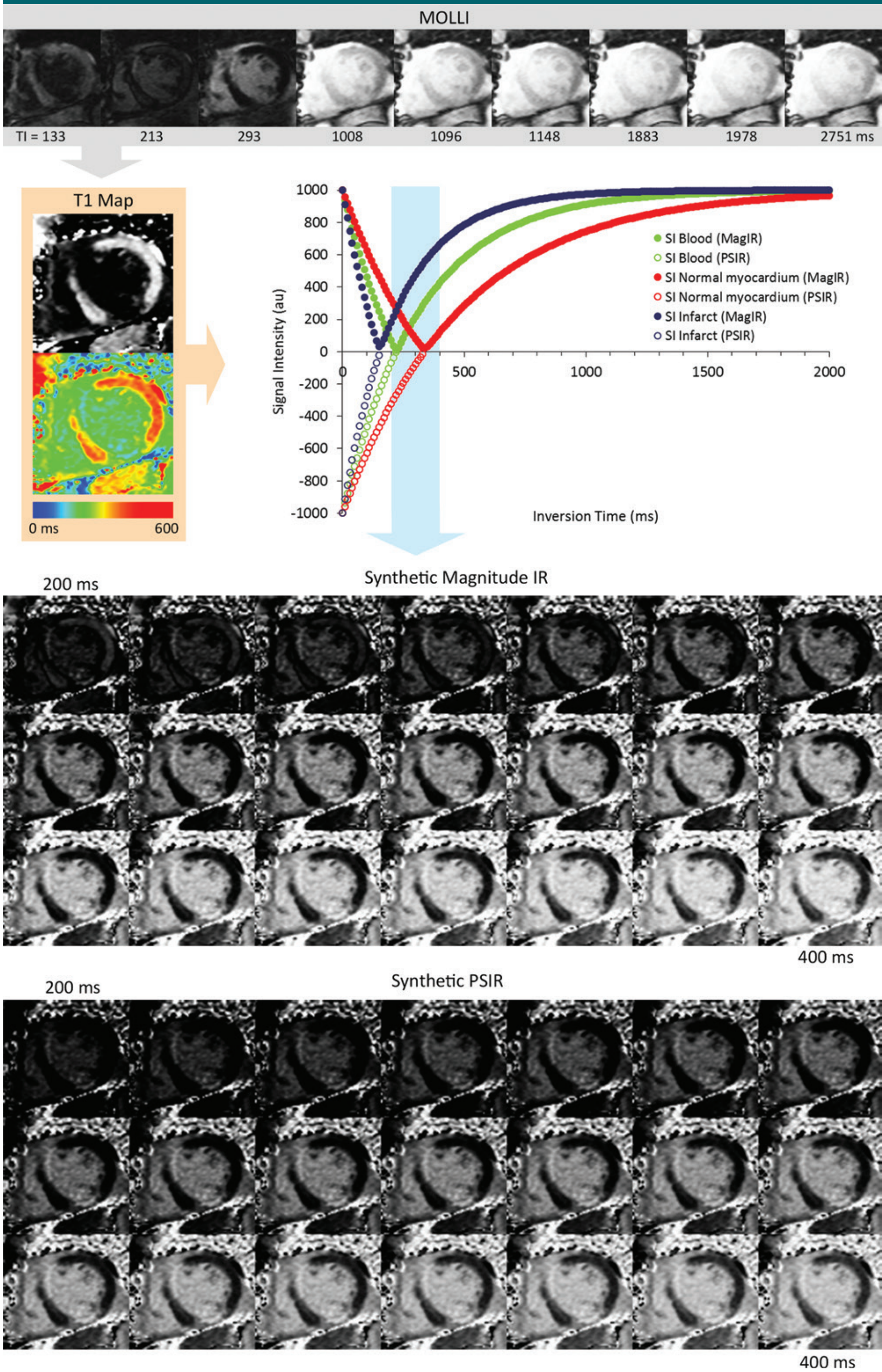

Figure 1: Process for generating synthetic IR images. Representative prototype MOLLI-based postcontrast T1 mapping in 54-year-old man with anteroseptal and inferior myocardial infarction is shown. Color-coded T1 map was generated by using three-parameter least-square curve fitting, a Look-Locker correction, and a further correction factor for imperfect inversion. From pixel-by-pixel T1 values, the signal intensity of each pixel can be calculated in both a magnitude and phase-sensitive fashion at any theoretic TI. Graph shows TI dependence of magnitude-reconstructed *(MagIR)* and phase-sensitive *(PSIR)* signal intensity *(SI)* in blood and normal and infarcted myocardium between TIs of 0 and 2000 msec at 10-msec increments. Magnitude-reconstructed and phase-sensitive IR images were reconstructed between TIs of 200 and 400 msec at 10-msec increments.

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Table 1

Summary of Patient Characteristics

Characteristic	Value
Age (y)*	54 ± 16
Sex	
M	25 (58)
F	18 (42)
Race	
Asian	2 (4.6)
African American	15 (35)
Caucasian	26 (60)
Weight (kg)*	78.0 ± 19.0
Height (cm)*	167.6 ± 9.7
Body mass index (kg/m^2)*	27.7 ± 7.2
Body surface area (m^2)*	1.9 ± 0.2
Diabetes mellitus	6 (14)
Hypertension	28 (65)
Dyslipidemia	7 (16)
Smoking	
Current	4 (9.3)
Previous	8 (19)
Previous percutaneous coronary intervention	4 (9.3)
Previous coronary artery bypass surgery	3 (6.9)

Note.—Except where indicated, data are numbers of patients (n = 43), with percentages in parentheses.

* Data are means ± standard deviations.

Figure 2

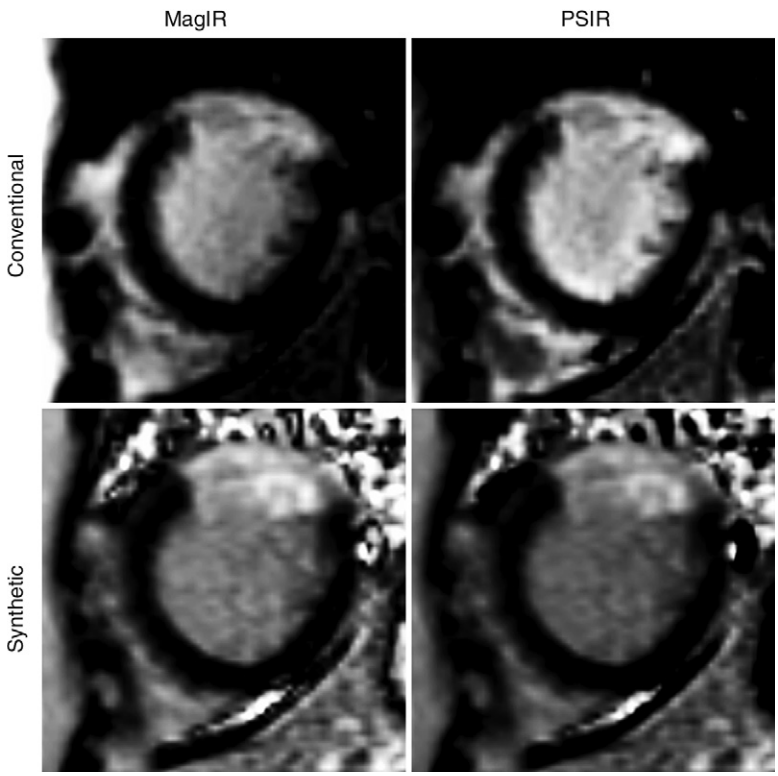

Figure 2: Representative conventional and synthetic magnitude-reconstructed *(MagIR)* and phase-sensitive *(PSIR)* IR short-axis images in 37-year-old woman with anterolateral myocardial infarction. The TI used for conventional IR image acquisition was retrospectively chosen to generate synthetic IR images from the T1 map.

was calculated, taking into account the pixel size information. This area was then expressed as the percentage of the total myocardial cross-sectional area in the particular section.

Statistical Analysis

Statistical analyses were performed by using software (MedCalc 13.2.2; MedCalc Software, Ostend, Belgium). The Kolmogorov-Smirnov test was used to assess normal distribution of the continuous data. Continuous variables are reported as means ± standard deviations and categoric variables as absolute frequencies and proportions. Synthetic magnitude-reconstructed and phase-sensitive techniques were compared with the conventional magnitude-reconstructed and phase-sensitive IR methods. Differences in the LGE detection rate between the synthetic and conventional techniques were analyzed with the McNemar test. Sensitivity and specificity were calculated on a per-patient and per-segment basis. Agreement with regard to the detection of LGE between readers was assessed by using linearly weighted κ statistics, with the level of agreement as follows: poor, κ < 0.20; fair, κ = 0.21–0.40; moderate, κ = 0.41–0.60; good, κ = 0.61–0.80; and excellent, κ > 0.81. Differences in LGE area obtained with the synthetic and conventional IR techniques were analyzed with the paired t test. Bland-Altman analysis was used to investigate agreement in LGE quantification and potential systematic differences between the approaches and between readers (12). $P < .05$ was considered indicative of a statistically significant difference.

Results

The characteristics of the 43 patients included in our study are detailed in Table 1. Figure 2 shows representative short-axis synthetic and conventional IR images with LGE in a patient with myocardial infarction.

At patient-based evaluation, LGE was detected on conventional magnitude-reconstructed and phase-sensitive IR images in 20 of the 43 patients (46%); 23 (53%) of the viability studies did not show LGE. The patterns of LGE were consistent with myocardial infarction in each case. The synthetic IR methods detected LGE in 19 of the 43 patients (44%); 24 patients were considered to have normal findings. The McNemar test revealed no significant difference in detection between the synthetic IR methods and the standard of reference. Synthetic magnitude-reconstructed and phase-sensitive IR approaches showed very high sensitivity and specificity compared

Table 2

Sensitivity and Specificity of Synthetic IR Techniques in the Detection of Myocardial LGE: Results of Per-Patient and Per-Segment Analyses

Analysis and Technique	Sensitivity (%)	Specificity (%)
Per patient		
Synthetic MagIR	90 (18/20) [68.3, 98.8]	96 (22/23) [78.1, 99.9]
Synthetic PSIR	90 (18/20) [68.3, 98.9]	96 (22/23) [78.1, 99.9]
Per segment		
Synthetic MagIR	94 (52/55) [84.9, 98.9]	99 (188/189) [97.1, 100.0]
Synthetic PSIR	94 (52/55) [84.9, 98.9]	99 (188/189) [97.1, 100.0]

Note.—Numbers in parentheses are raw data. Numbers in brackets are the 95% confidence interval. MagIR = magnitude-reconstructed IR, PSIR = phase-sensitive IR.

Table 3

Quantitative LGE Parameters in Patients in Whom LGE Was Observed with All Techniques (n = 17)

Technique	Infarct Area (cm^2)	Infarct Fraction (%)
Synthetic MagIR	4.35 ± 1.88	18.10 ± 8.86
Synthetic PSIR	4.14 ± 1.62	17.23 ± 7.67
Conventional MagIR	4.25 ± 1.92	17.81 ± 9.53
Conventional PSIR	4.22 ± 1.86	17.71 ± 9.26

Note.—Data are means ± standard deviations. MagIR = magnitude-reconstructed IR, PSIR = phase-sensitive IR.

with the conventional IR approaches, ranging from 90% to 99% (Table 2). In two cases (4.7%), synthetic techniques did not depict an infarct area that was detectable with the conventional approaches, and in one case (2.3%), the synthetic methods showed myocardial LGE and conventional imaging did not.

At segment-based analysis, 244 segments (six segments per section in 36 cases and four segments per section in seven cases) were evaluated. LGE was detected with both standard of reference techniques in 55 of the 244 segments (22.5%), whereas 189 (77.5%) were considered normal. Both synthetic techniques detected LGE in 53 of the 244 segments (21.7%), whereas 191 segments (78.3%) showed no LGE (P > .05 when compared with standard of reference). Segment-based sensitivity and specificity for LGE detection with the synthetic techniques are shown in Table 2.

In patients with LGE, the synthetic and conventional IR techniques yielded similar areas of infarct, ranging from 4.14 to 4.35 cm^2, and similar infarcted percentage of myocardium (17.23%–18.10%), with small systematic differences (Table 3, Fig 3). The 95% limits of agreement were similar for the phase-sensitive IR and magnitude-reconstructed techniques.

Interreader agreement with regard to the detection of LGE with the different IR approaches is summarized in Table 4. The interreader agreement for the detection of LGE was excellent. Results from Bland-Altman analysis regarding the area of LGE and infarcted percentage of myocardium for the two readers are also shown in Table 4. There was a small systematic difference for the infarct fraction between the readers. The 95% limits of agreement had similar magnitude as for the intermethod comparison. Synthetic phase-sensitive IR showed the smallest systematic bias and variability.

Discussion

In our prospective MR imaging study, we investigated the diagnostic accuracy of T1 mapping–based synthetic IR imaging in the detection of LGE and assessed the accuracy of infarct quantification with this technique compared with conventional single-shot LGE approaches. Our initial results indicate that LGE detection and quantitative infarct assessment with the synthetic magnitude-reconstructed and phase-sensitive IR techniques are comparable to that with the conventional IR methods. With these synthetic algorithms, quantification of LGE could be performed on the basis of T1-derived data when T1 mapping with full left ventricle coverage becomes available. This may allow for more consistent image quality by omitting technologist input in the acquisition of traditional LGE IR sequences and may reduce operator dependence of this application by suboptimal TI selection.

Synthetic IR approaches could depict LGE with high sensitivity and specificity. The performance parameters did not differ between the magnitude-reconstructed and phase-sensitive IR techniques at either per-patient or per-segment analysis. The reason for the identical accuracy might be the underlying method of image generation, that is, both the synthetic magnitude-reconstructed and synthetic phase-sensitive IR images are calculated from the same T1 map. There were two cases in which LGE was depicted with the conventional methods but not with either the synthetic magnitude-reconstructed technique or the synthetic phase-sensitive IR technique. The heart rate was higher than 90 beats per minute in both patients who required the use of reduced image resolution for T1 mapping. Further investigation is necessary to clarify the effect of spatial resolution on diagnostic accuracy. In one patient, an area of LGE was detected on the synthetic images but not on the conventional images. This artifact was considered the consequence of insufficient motion correction and image misregistration during T1 fitting. Interreader statistics showed excellent agreement in the detection of LGE with all four IR methods.

Our results indicate that quantification of LGE with synthetic IR imaging is feasible in patients with previous myocardial infarction. Myocardial infarct

Figure 3

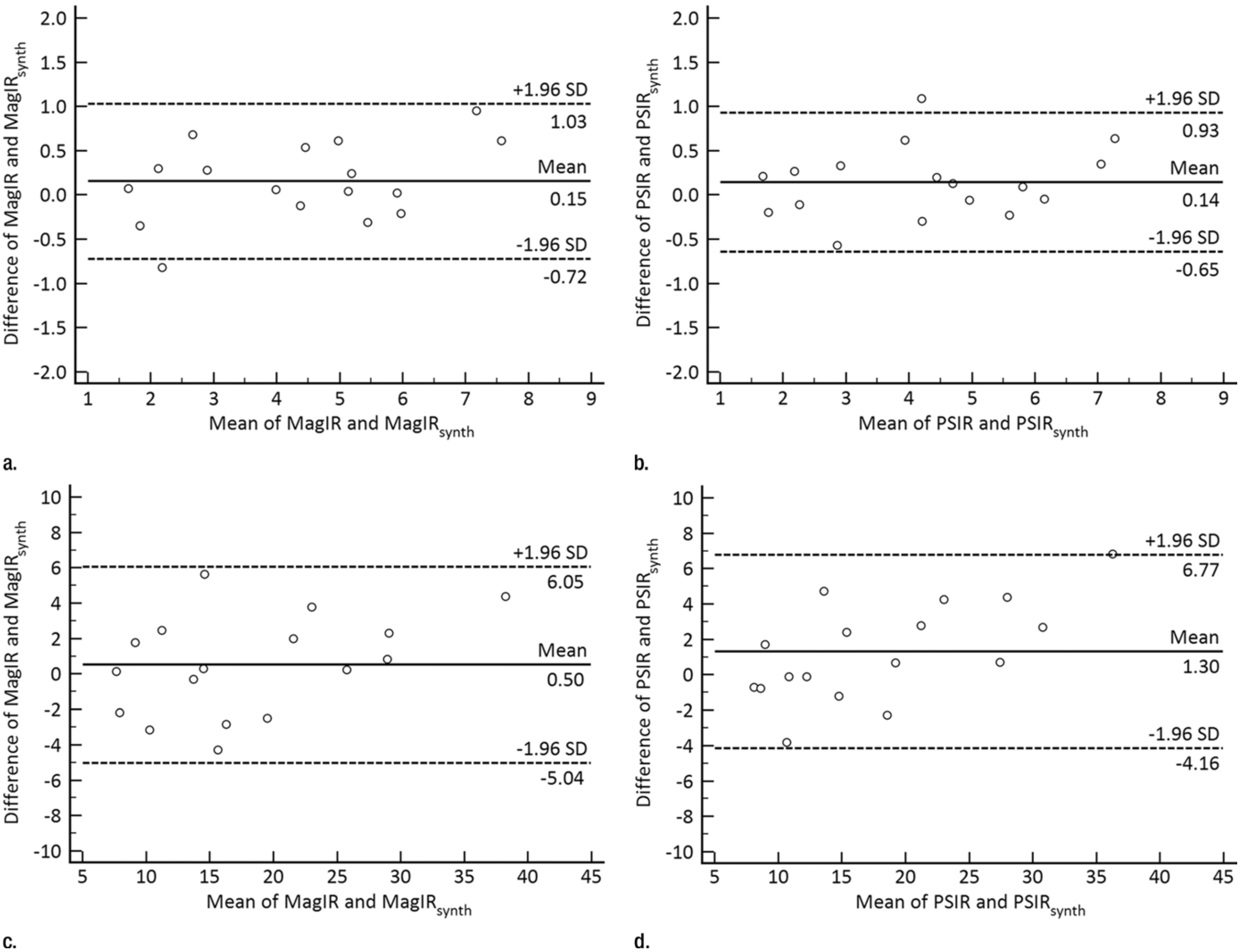

Figure 3: Bland-Altman plots show comparison of **(a, b)** LGE area (in square centimeters) and **(c, d)** LGE fraction (LGE area normalized to total myocardial area of section) with conventional magnitude-reconstructed *(MagIR)* and phase-sensitive *(PSIR)* IR techniques and synthetic magnitude-reconstructed *(MagIR$_{synth}$)* and phase-sensitive *(PSIR$_{synth}$)* IR techniques. Data measured by the two readers were averaged. Dashed lines show the 95% limits of agreement (±1.96 standard deviations), and solid line shows mean of differences (ie, systematic bias).

Table 4

Interreader Agreement with Regard to LGE Detection and Quantification

	LGE Detection*			
Technique	Per-Patient Analysis	Per-Segment Analysis	LGE Area (cm^2)†	Infarct Fraction (%)†
Synthetic MagIR	0.859 (0.706, 1.000)	0.928 (0.871, 0.985)	0.40 (−1.20, 1.99)	1.75 (−7.37, 10.86)
Synthetic PSIR	0.906 (0.778, 1.000)	0.939 (0.887, 0.992)	−0.08 (−0.94, 1.09)	−0.38 (−5.02, 5.78)
Conventional MagIR	0.859 (0.706, 1.000)	0.928 (0.871, 0.985)	0.19 (−2.19, 1.81)	−0.39 (−9.34, 8.56)
Conventional PSIR	0.860 (0.708, 1.000)	0.918 (0.859, 0.978)	−0.34 (−2.16, 1.47)	−1.16 (−9.67, 7.35)

Note.—MagIR = magnitude-reconstructed IR, PSIR = phase-sensitive IR.

* Data are κ values. Numbers in parentheses are the 95% confidence interval.

† Data are biases and were obtained with Bland-Altman analysis. Numbers in parentheses are the 95% limits of agreement.

quantification with synthetic IR imaging did not show significant differences compared with the standard of reference in our study (conventional IR imaging). Because our study was conducted in patients clinically referred for myocardial viability assessment with MR imaging, we did not have an independent non-MR imaging standard of reference with which to validate our measurements. For LGE quantification, we used a threshold of 5 standard deviations above the average signal intensity of the normal myocardium. This threshold is higher than the conventionally used cut-off (13,14) because the 2 standard deviation threshold has been found to overestimate infarct size (10,15). The reason for overestimation is mainly because of the partial volume effects affecting the border zone of the infarct (16,17). The 5 standard deviation threshold used herein has been found to be the most accurate among the binary quantification techniques (11). Although our semiautomated analysis required substantial manual input, Bland-Altman analysis–based interreader results indicated that the systematic bias in the quantitative evaluation was negligible. However, the 95% limits of agreement were found to be somewhat higher than in intermethod comparison, which is suggestive of slightly higher variability owing to observer-related factors.

In our study, synthetic IR image calculation was performed with an application developed in-house. Synthetic IR images can also be generated with the prototype MOLLI protocol; however, the TI range (200–1200 msec) and temporal resolution (25 msec) that these images cover are not optimal for LGE evaluation. To overcome this limitation, we designed a software application that enables the calculation of synthetic images in any TI range at any increment of milliseconds.

Practical Implications

There are at least two potential major advantages of synthetic IR imaging. First, the generation of synthetic images does not require additional imaging because these images are derived from T1 maps. With the increasing availability and application of T1 mapping, synthetic IR images may eliminate the need for conventional LGE acquisitions if and when T1 mapping with full left ventricle coverage is integrated into clinical routine. Because synthetic images can be generated on the imaging unit within seconds immediately after the acquisition, an initial evaluation can be obtained while the patient is still in the magnet. Although T1 mapping has been shown to have incremental value over LGE IR imaging in several cardiac disorders (18–22), we believe that the established body of evidence for the diagnostic and prognostic value of LGE, as well as the standardization of the LGE technique, currently outweighs that of T1 mapping.

The second advantage of the synthetic technique is the possibility of retrospective review of the entire TI range and the selection of the most optimal TI. With the selection of the appropriate TI, the normal myocardium is nulled to maximize the contrast between the normal and diseased myocardium. If magnitude-reconstructed images are acquired by using a suboptimal TI, the results are reduced contrast and inaccurate quantitative measurements (2,23). Because the optimal TI is dependent on several individual factors (including contrast agent wash-in and washout rates and the time delay after contrast material administration), an additional sequence must be performed in every patient before LGE imaging (23). Although the phase-sensitive IR technique provides consistent contrast over a wide TI range with use of a nominal TI value (2), it only recently became vendor independent, and we believe that magnitude-reconstructed imaging may still be the predominantly used approach in clinical practice. In contrast to the prospective selection of the TI, synthetic IR images can be retrospectively generated at any theoretic TI. In this study, we generated the synthetic images within the clinically relevant TI range (200–400 msec) at 10-msec increments. The retrospective selection of the TI provides the possibility to choose the most optimal image for LGE evaluation. Even if the acquisition of an entire short-axis stack takes 5–6 minutes, resulting in a typical TI increase of 15–25 msec (2), the optimal TI can be adjusted retrospectively, if desired, on an image-by-image basis. Such an approach would eliminate the need for technologists to optimize the LGE acquisition (eg, by obtaining a TI scout view before LGE imaging and readjusting the TI owing to the time elapsed) and reduce operator dependence and variability in image quality.

Limitations

The major limitation of our study is that LGE evaluation was based on a single-section acquisition unsuitable for the quantification of the total volume LGE in the left ventricle. This single short-axis section was selected on the basis of the conventional LGE short-axis stack. The single-section acquisition may introduce potential bias because the conventional LGE and T1 acquisitions were performed during two different breath holds. Thus, the level of expiration might be different, resulting in slightly different section positioning. The reason for using single-section T1 mapping was the time-consuming nature of the currently available T1 mapping approaches. Because complete left ventricle multisection T1 mapping may take 5–6 minutes, the T1 map acquired with such a long delay after the conventional LGE acquisition would reflect a different postcontrast environment. In our proof of concept study, we aimed to determine the feasibility of myocardial infarct detection and quantification by using synthetic IR imaging, which required the shortest delay possible between the acquisitions. With the expected future availability of a fast three-dimensional T1-mapping sequence (24), our results can be extended to a validation study involving coverage of the entire left ventricle. Because the prevalence of infarct and, thus, LGE in this population was rather high, the observed per-patient diagnostic accuracy of synthetic IR imaging may be somewhat overestimated. Larger studies among patients with a larger range of coronary artery disease severity should be performed to confirm our results. In this study, single-shot IR acquisition was chosen as the reference technique because it provides comparable spatial resolution to that of single-shot IR-based T1 mapping. Thus, the accuracy of the synthetic techniques compared with high-spatial-resolution segmented IR imaging is unclear. Further limitations are that we did not evaluate the time necessary to acquire and analyze the images and only studied a small patient cohort with ischemic heart disease; thus, the ability of this technique to depict LGE in the whole spectrum of myocardial diseases is unclear and must be explored further. LGE was also not evaluated on the basis of transmurality and patchiness.

In conclusion, synthetic IR cardiac MR images can be derived from T1 maps without additional imaging time and provide the same diagnostic and quantification accuracy as conventional IR techniques.

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