

3.0T Contrast-enhanced whole-heart coronary magnetic resonance angiography for simultaneous coronary artery angiography and myocardial viability in chronic myocardial infarction

A single-center preliminary study

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Abstract

To evaluate the accuracy of contrast-enhanced whole-heart magnetic resonance coronary angiography at 3.0T for assessing significant stenosis ($\geq 50\%$ lumen diameter reduction) in patients with myocardial infarction, by using conventional coronary artery angiography as the reference standard, and also test the performance of that for the detection and assessment of chronic myocardial infarction (MI), compared with standard delayed-enhancement coronary magnetic resonance (DE-CMR) for the determination of infarct size.

We studied 42 consecutive patients (37 men, 5 women, mean age 58.5 ± 10.7 years) with MI scheduled for conventional coronary angiography. Contrast-enhanced whole-heart coronary magnetic resonance angiography (CMRA) was employed after sublingual nitroglycerin (NTG) with the abdominal banding rolled tightly along the side of ribs. Finally, a 3D phase-sensitive inversion-recovery gradient-echo (3D-PSIR-GRE) sequence was performed during free breathing. The assessment of MI sizes on WH-CMRA reconstructed images and 3D-PSIR-GRE images were compared using a paired student *t* test.

The acquisition of CMRA was completed in 40 (95.2%) of 42 patients, with an imaging time averaged at 9.5 ± 3.1 minutes. The average navigator efficiency was 47%. The sensitivity, specificity, and positive and negative predictive values of whole-heart CMRA for the detection of significant lesions on a segment-by-segment analysis were 91.7% (95% confidence interval [CI] 83.8–96.1), 84.0% (95% CI 80.0–87.4), 57.9% (95% CI 50.0–65.8), 97.7% (95% CI 95.3–98.9), respectively, and on a patient-based analysis 93.5% (95% CI 77.2–98.9), 88.9% (95% CI 50.7–99.4), 96.7% (95% CI 80.9–99.8), and 80.0% (95% CI 44.2–96.5), respectively. Infarcts were generally higher on the CE-CMRA technique compared with the standard technique (18.0 ± 7.2 cm³ vs 16.1 ± 6.4 cm³; $P < .0001$).

Contrast-enhanced whole-heart CMRA with 3.0-T not only may permit reliable detection of significant obstructive coronary artery disease in patients with myocardial infarction, but also could identify and quantify the volume of myocardial infarction. This technique could be considered the preferred approach in patients who could not overcome longer scanning times or unable to hold their breath instead of delayed-enhancement magnetic resonance imaging for detection of infarcted myocardium. However, compared with standard imaging, the volume of myocardial infarction is slightly overestimated.

Abbreviations: 3D-PSIR-GRE = 3D phase-sensitive inversion-recovery gradient-echo, CAD = coronary artery disease, CCA = coronary artery angiography, CE-CMRA = contrast-enhanced coronary magnetic resonance angiography, CNR = contrast-to-noise ratio, CTA = computed tomography angiography, DE-MRI = delayed-enhancement magnetic resonance imaging, ECG = electrocardiography, FLASH = fast low-angle shot, GRE = gradient-recalled echo, ICA = invasive coronary angiography, LGE = late gadolinium enhancement, LV = left ventricle, MI = myocardial infarction, PSIR = phase-sensitive inversion recovery, SNR = signal-to-noise ratio, SSFP = steady-state free precession.

Keywords: chronic myocardial infarction, coronary angiography, magnetic resonance imaging

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All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent was obtained from all individual participants included in the study. The authors declare no conflicts of interest.

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1. Introduction

In recent years, cardiac magnetic resonance imaging (MRI) is a promising method for a comprehensive, multipurpose non-invasive evaluation of coronary artery disease (CAD). The breadth of applications possible with cardiac MRI allows combined non-invasive assessment of coronary imaging, myocardial perfusion, function and myocardial viability. A previous study has demonstrated the feasibility of the accurate detection of significant stenosis in coronary arterial segments of ≥ 1.5 mm using a spoiled gradient-echo sequence (FLASH) at 3.0-T with slow infusion of a high relaxivity clinical contrast media Gd-BOPTA.^[1] With this method, coronary magnetic resonance angiography (CMRA) not only has significantly reduced acquisition time and improved the contrast-to-noise ratio (CNR) in delineating small coronary branches, but also showed the myocardial viability due to high relaxivity contrast agent. Moreover, delayed-enhancement magnetic resonance imaging (DE-MRI) is a well established noninvasive imaging modality that allows assessment of myocardial infarct size.^[2–4] Yet, until now, there has been less direct comparison between these two approaches in patients with myocardial infarction. Thus, the purpose of this study was to compare the results of contrast-enhanced coronary magnetic resonance angiography (CE-CMRA) with those of invasive coronary angiography (ICA), and also test the performance of that for the detection and assessment of chronic myocardial infarction (MI), compared with standard delayed-enhancement coronary magnetic resonance (DE-CMR) for the determination of infarct size.

2. Methods

Patients: The study population consisted of patients with documented chronic MI in their medical history according to the recent joint European Society of Cardiology/American College of Cardiology consensus document for the redefinition of MI.^[5] Thus, patients had typical rise and fall of cardiac biomarkers with either appropriate electrocardiography (ECG) changes, ischemic symptoms, or both at the time of the acute event. All patients scheduled to undergo whole-heart CMRA and subsequent ICA between January 2009 and November 2010 (Fig. 1). Both examinations were performed within a time interval of 12 days (mean 2 days).

Exclusion criteria included general contraindications to MR examination (claustrophobia, pacemaker), absence of a sinus cardiac rhythm, orthopnea, impaired renal function (serum creatinine > 120 $\mu\text{mol/L}$), presence of coronary stent and previous coronary artery bypass graft surgery.

The study protocol had our institutional review board approval, and all patients gave informed consent to participate in the study.

2.1. Patient preparation

A β -blocker (metoprolol tartrate, 25–50 mg) was given orally to patients with heart rate > 75 bpm before CMRA. 0.5 mg Nitroglycerin sublingually was administered to any subject before CMRA. Medical abdominal belt was rolled tightly along the side of the ribs to reduce the abdominal movement during deep inspiration.

2.2. Magnetic resonance data acquisition

Contrast-enhanced whole-heart coronary MRA was performed on a 3.0T whole-body scanner (Trio; Siemens Medical Solutions, Erlangen, Germany) with a 12-channel matrix coil (6 each, dorsally, and ventrally). The R-wave acquired from a 3-lead

wireless vectorcardiogram was used to trigger the data acquisition. The cardiac MR protocol was as follows: after initial localization of 2-chamber and 4-chamber view and left ventricular short-axis view. Then a retrospective electrocardiography (ECG)-triggered cine—a fast low-angle shot (FLASH) sequence with 80 cardiac phases—was performed in the 4-chamber plane to determine the quiescent period for coronary artery imaging. This cine scan was visually assessed to calculate the patient-specific trigger-delay time and duration of data acquisition. For contrast-enhanced (CE) whole-heart CMRA, a prospective navigator-gated, ECG-triggered, fat-saturated, inversion recovery-prepared, segmented, three-dimensional FLASH sequence (TR 320 ms, TE 1.4 ms; Flip angle 20°; matrix 256X256, FOV 220 X330, acquired voxel size = 1.3 X1.3X0.9 mm³ and interpolated to 0.65 X0.65X0.45 mm³) was employed. The 3-dimensional k-space data were collected with a centric ordering scheme in the phase-encoding direction and a linear order scheme in the partition-encoding direction. In addition, a nonselective inversion pulse (TI = 200 ms) was applied before the navigator echo pulses to suppress the background tissues. To speed up the image acquisition, parallel data acquisition (generalized auto-calibrating partially parallel acquisitions) was used in the phase-encoding direction with an acceleration factor of 2. A 0.2 mmol/kg intravenous injection of contrast agent (Gadobenate dimeglumine, Multi-Hance; Bracco Imaging SpA, Milan, Italy) was administered into an antecubital vein using a power injector at a rate of 0.3 mL/s, immediately followed by 20 mL saline given at the same rate. Data acquisition began 60 seconds after the initialization of contrast agent administration.

Finally, delayed contrast-enhanced (DCE) images were also obtained using a 3D phase-sensitive inversion-recovery gradient-echo pulse sequence during free breathing (TI = 250–400 ms, decided by TI scout).

2.3. Coronary MR image analysis

Source coronary MR angiograms were reformatted using image processing software (InSpace; Siemens Medical Solutions, Erlangen, Germany), and patient information was removed.

In addition, CoronaViz software (Siemens Corporate Research, Princeton, New Jersey) were used for CMRA images to project multiple vessels onto a single image.^[6] For each segment, the image quality was graded using the following scale: 1, poor (coronary artery with markedly blurred borders); 2, good (coronary artery visible with moderately blurred borders); 3, very good (coronary artery visible with slightly blurred borders); and 4, excellent (coronary artery visible with sharply defined borders). The intention-to-diagnose approach was used, and nonassessable segments were considered to have a stenosis.^[7] Images of good, very good, and excellent quality (grades 2, 3, and 4) were further classified according to the visual assessment of the coronary-artery lumen as clinically significant disease. Significant coronary artery stenosis was defined as a reduction in luminal diameter of at least 50%. Two experienced readers who were blinded to the ICA results independently assessed coronary MR angiography by using axial source images, multiplanar reformatting, and thin-slab sliding maximum intensity projection images. Disagreement between 2 observers was settled by a consensus reading.

2.4. Infarction volume

The MI areas of CE-CMRA and late enhancement defined as nonviable tissue with hyperenhancement were first identified

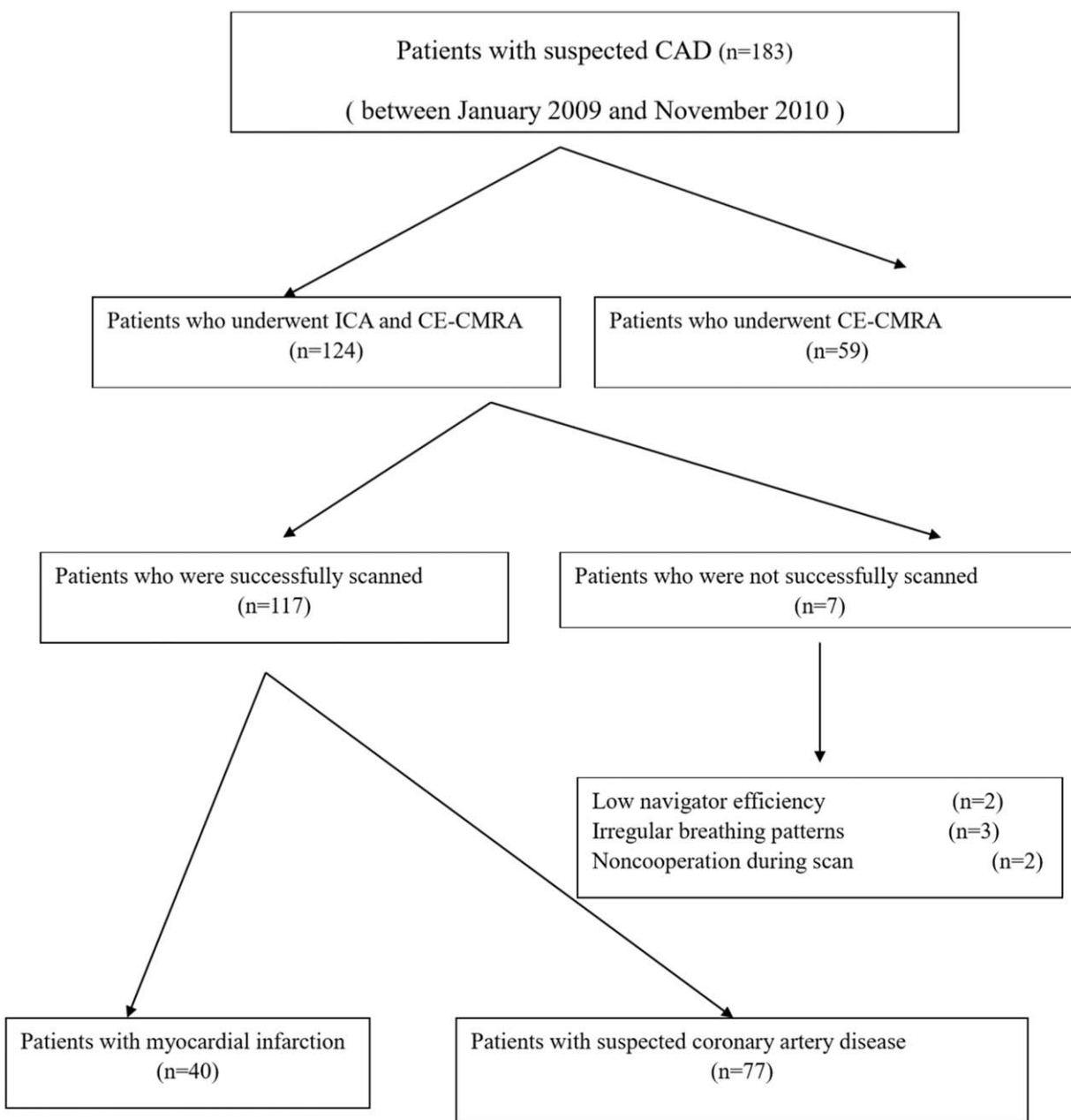


Figure 1. Flow chart of patient inclusion.

visually on short-axis orientation. Then, the outer contours of the hyperenhanced areas were manually traced, and the single slice areas were multiplied by the particular slice distance and summed.^[8–10] Mean values, based on the 2 readers' measurements, were used for statistical analysis.

2.5. Conventional coronary angiography

Conventional x-ray coronary angiography served as the reference standard in this study. Selective biplane coronary angiograms in multiple orthogonal projections were evaluated by 2 cardiologists in consensus who were blinded to the coronary MR angiography results. All segments of the coronary artery tree with a reference diameter of 1.5 mm or greater were included in the study. Segments were classified as normal (smooth parallel or tapering

borders), as having nonsignificant disease (luminal irregularities or <50% diameter stenosis), or as having significant stenoses (≥50% diameter stenosis).

2.6. Statistical analysis

Patient data were documented by the departments of diagnostic imaging and cardiology of our institution. Continuous variables were presented as means and standard deviations and categorical variables as percentages. Sensitivity, specificity, positive predictive value, and negative predictive value with 95% CIs were calculated on a per-segment, per-vessel, and per-patient basis using invasive x-ray coronary angiography as reference standard. Inter- and intraobserver variability for the image quality grading and the detection of significant coronary artery stenosis was

Table 1
Characteristics of the Patients.

Characteristics	Patients who underwent CMRA (42)	Patients with successful CMRA (40)
Male/female	37/5	35/5
Age, y	58.5±10.7	58.1±10.9
Range	32–76	32–76
Heart rate, beats/min	65.3±9.1	64.8±9.2
Range	52–90	52–90
Body weight, kg	62.3±10.1	62.2±10.2
Current or prior cigarette smoking,	37 (88%)	35 (87%)
Hypertension	17 (40%)	16 (40%)
Hypercholesterolemia	7 (17%)	7 (18%)
Diabetes	10 (24%)	9 (23%)
Stenosis on coronary angiography,	33 (79%)	31 (78%)
One-vessel disease	6	6
Two-vessel disease	9	8
Three-vessel disease	15	14
Four-vessel disease	3	3

Values are n (%) or mean ±SD.

CMRA=coronary magnetic resonance angiography.

calculated using kappa statistics. The assessment of MI sizes on WH-CMRA reconstructed images and 3D-PSIR-GRE images were compared using a paired student *t* test. Bland-Altman^[11] and linear regression analyses were performed to assess the relationship between the two imaging methods for infarct size. A 2-sided *P* < .05 was considered statistically significant for all tests.

3. Results

The study population characteristics are summarized in Table 1. Both CE-CMRA and DE-MRI were performed without complications in all 42 patients. The MI locations were detected by 2 techniques in all patients. Acquisition of whole-heart coronary MR angiography was successfully completed in 40 (95.2%) of 42 patients. Two patients were aborted for the following reasons: one because of low navigator efficiency of less than 20%, one because of having a sudden cough, leading to drift of the diaphragm position. Mean heart rate during CMRA was (62 ± 10) beat/min. Acquisition time of contrast-enhanced CMRA was 9.5 ± 3.1 minutes, the navigator efficiency and image quality was 47% ± 11% and 3.2 ± 0.7, respectively. The mean acquisition time for the 3D-PSIR-GRE was 8.4 ± 0.5 minutes.

The CMRA image quality of 40 patients is summarized in Table 2. Four hundred and ninety-six segments had a reference luminal diameter greater than 1.5 mm on ICA images, 440 of which (89%) were assessable on coronary MR angiography images (score 2–4). In the remaining 11% (n = 56) of segments, evaluation was compromised by motion artifacts, low contrast-to-noise ratio, or small vessel size. Inter- and intraobserver variability for the image quality grading had kappa values of 0.85 and 0.89, respectively.

3.1. Diagnostic performance of CMRA compared with QCA

The diagnostic performance of CMRA to detect significant stenoses on a patient-, segment-, and vessel-based analysis is detailed in (Table 3).

Table 2
Image Quality of 40 Patients With Successful CMRA.

Artery	No. of segments >1.5 mm on QCA	No. of assessable segments on CMRA	Image quality of CMRA
LM	40	40 (100%)	3.7 ± 0.7
LAD			
Proximal	40	39 (98%)	3.7 ± 0.7
Middle	39	38 (97%)	3.6 ± 0.6
Distal	36	34 (94%)	3.0 ± 0.4
Diagonal branches	42	31 (74%)	2.8 ± 0.6
LCX			
Proximal	40	39 (98%)	3.0 ± 0.8
Distal	32	27 (84%)	2.9 ± 0.5
Marginal branches	47	30 (64%)	2.7 ± 0.8
RCA			
Proximal	40	39 (98%)	3.7 ± 0.7
Middle	39	38 (95%)	3.6 ± 0.7
Distal	37	34 (92%)	3.1 ± 0.7
PDA/PL	64	51 (80%)	2.6 ± 0.7
Total	496	440 (89%)	3.2 ± 0.7

CMRA=coronary magnetic resonance angiography, LAD=left anterior descending coronary artery, LCX=left circumflex coronary artery, LM=left main coronary artery, PDA/PL=posterior descending artery/posterolateral branch, QCA=quantitative coronary angiography, RCA=right coronary artery.

On per patient basis, coronary MR angiography helped to correctly identify clinically significant CAD in 29 (sensitivity 93.5%) of 31 patients (Fig. 2), and correctly rule out clinically significant CAD in 8 (specificity 88.9%) of 9 patients (Fig. 3).

In a total of 440 assessable coronary segments, QCA detected a total of 86 lesions (≥50%). CMRA correctly identified 78 of these lesions (sensitivity 90.7%). In 336 segments, stenosis was ruled out correctly by CMRA (specificity 94.9%). The main reason for false positive and false negative was poor spatial resolution combined with motion artifact. The kappa value of inter- and intraobserver variability for coronary artery stenosis detection was 0.84 and 0.90, respectively.

Table 3
Diagnostic performance of 3.0-T contrast-enhanced whole-heart CMRA in grading stenoses 50% on per-segment, per-vessel, and per-patient basis.

Analysis and parameter	All segments	Assessable segments
Per segment	n = 496	n = 440
Sensitivity	91.7 (88/96) [83.8–96.1]	90.7 (78/86) [82.0–95.6]
Specificity	84.0 (336/400) [80.0–87.4]	94.9 (336/354) [91.9–96.9]
PPV	57.9 (88/152) [50.0–65.8]	81.3 (78/96) [71.7–88.2]
NPV	97.7 (336/344) [95.3–98.9]	97.7 (336/344) [95.3–98.9]
Per vessel	n = 160	n = 151
Sensitivity	93.4 (71/76) [84.7–97.6]	92.9 (65/70) [83.4–97.3]
Specificity	88.1 (74/84) [78.8–93.8]	91.4 (74/81) [82.5–96.2]
PPV	87.7 (71/81) [78.0–93.6]	90.3 (65/72) [80.4–95.7]
NPV	93.7 (74/79) [85.2–97.6]	93.7 (74/79) [85.2–97.6]
Per patient	n = 40	n = 39
Sensitivity	93.5 (29/31) [77.2–98.9]	93.3 (28/30) [76.5–98.8]
Specificity	88.9 (8/9) [50.7–99.4]	88.9 (8/9) [50.7–99.4]
PPV	96.7 (29/30) [80.9–99.8]	96.5 (28/29) [80.4–99.8]
NPV	80.0 (8/10) [44.2–96.5]	80.0 (8/10) [44.2–96.5]

Data are percentages, with raw data in parentheses and 95% CI in brackets. CI = confidence intervals, CMRA=coronary magnetic resonance angiography, NPV=negative predictive value, PPV=positive predictive value.

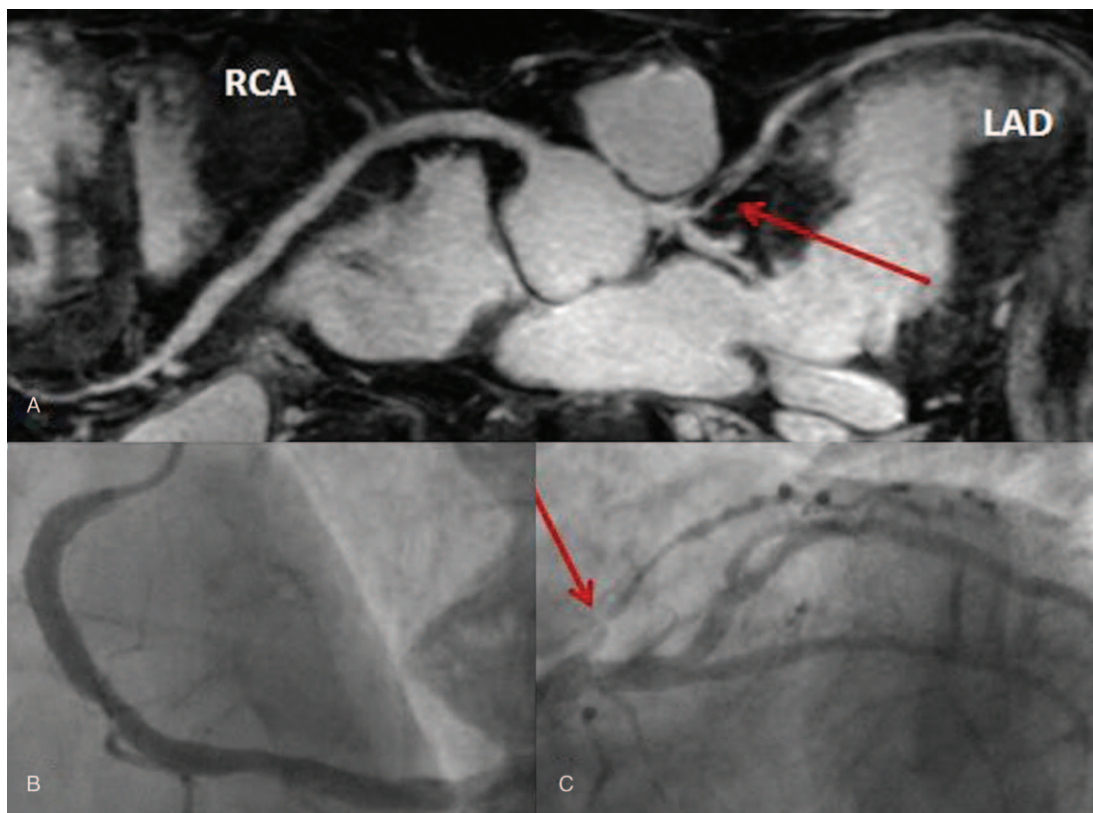


Figure 2. A patient with a significant stenosis in the proximal LAD. (A) Curved multiplanar reconstruction image shows a severe stenosis in the proximal LAD (arrow). (B, C) Conventional coronary angiography of the same artery confirms a stenosis of LAD (arrow).

3.2. Analysis of myocardial infarction: 3D-FLASH CE-CMRA compared with 3D-PSIR-GRE

Detailed results from CE-CMRA and 3D-PSIR-GRE are listed. Infarcts were generally higher on the CE-CMRA technique compared with the standard technique ($18.0 \pm 7.2 \text{ cm}^3$ vs $16.1 \pm 6.4 \text{ cm}^3$; $P < .0001$). Representative examples are shown in Figure 4.

By linear regression analysis, the assessment of the volume of the myocardial infarction showed good correlation ($r=1.00$, $P < .001$). A scatter diagram is shown in Figure 5A with a calculated regression equation of $y = -0.02794 + 1.1158x$. By Bland-Altman analysis, the average overestimation of infarct size by the CE-CMRA technique was 5.0%. The plot, however, revealed systematic bias between 2 methods, with a mean difference of 1.84 cm^3 (95% confidence interval [CI] 1.57 to 2.11) and limits of agreement between 0.17 and 3.51 cm^3 (Fig. 5B).

4. Discussion

The main finding of this study was that MI could be accurately detected (accuracy 92.5%) with the use of a navigator-gated, ECG-triggered, fat-saturated, inversion-recovery prepared segmented 3-dimensional FLASH sequence during free breathing. Importantly, CE-CMRA could depict 29 of the 31 significant coronary artery stenoses, which indicated the value of this approach in the assessment of patients with myocardial infarction. In addition, the negative predictive values based on per-segment-, vessel-, and -patient analyses were 97.7%, 93.7%, and 80.0%, respectively, suggesting that CE-CMRA may allow

reliable exclusion of significant stenoses before conventional coronary angiography. The other finding of this study was that MI may be detected with the use of this technique. However, there was a tendency to overestimate global infarct size, compared with the referenced 3D-PSIR-GRE sequence. This is probably attributable to the shorter scan time, resulting in slower wash-out amounts of contrast material in infarcted myocardium than in DE-CMR due to different acquiring time window. Delayed enhancement imaging by MR is typically performed 10 to 20 minutes after intravenous administration of gadolinium-containing contrast material using T1-weighted inversion recovery (IR) sequences.^[3,12-14] Previous studies demonstrated DE-CMR can provide accurate and reproducible diagnosis of both acute and chronic MI.^[15,16] Furthermore, even small subendocardial infarcts can be detected reliably in the absence of Q waves.^[16-18] For Coronary CE-MRA, our data acquisition was started 60 seconds after the initialization of contrast agent administration. However, the total scanning time was about 10 minutes, leading to increasing the wash-out amounts of Gd-BOPTA. Therefore, our study showed the possibility of acquiring coronary artery stenosis and infarcted myocardium data in a single sequence.

In the current study, both CE-CMRA and 3D-PSIR-GRE were employed at 3.0T for data acquisition during free breathing using conventional spoiled gradient-recalled echo (3D-FLASH). Compared to SSFP^[19], FLASH is relatively insensitive to B0 field inhomogeneities due to its spoiled gradient structure. Therefore, the comparison in the imaging of myocardial viability between two sequences can be summarized in several advantages. First,

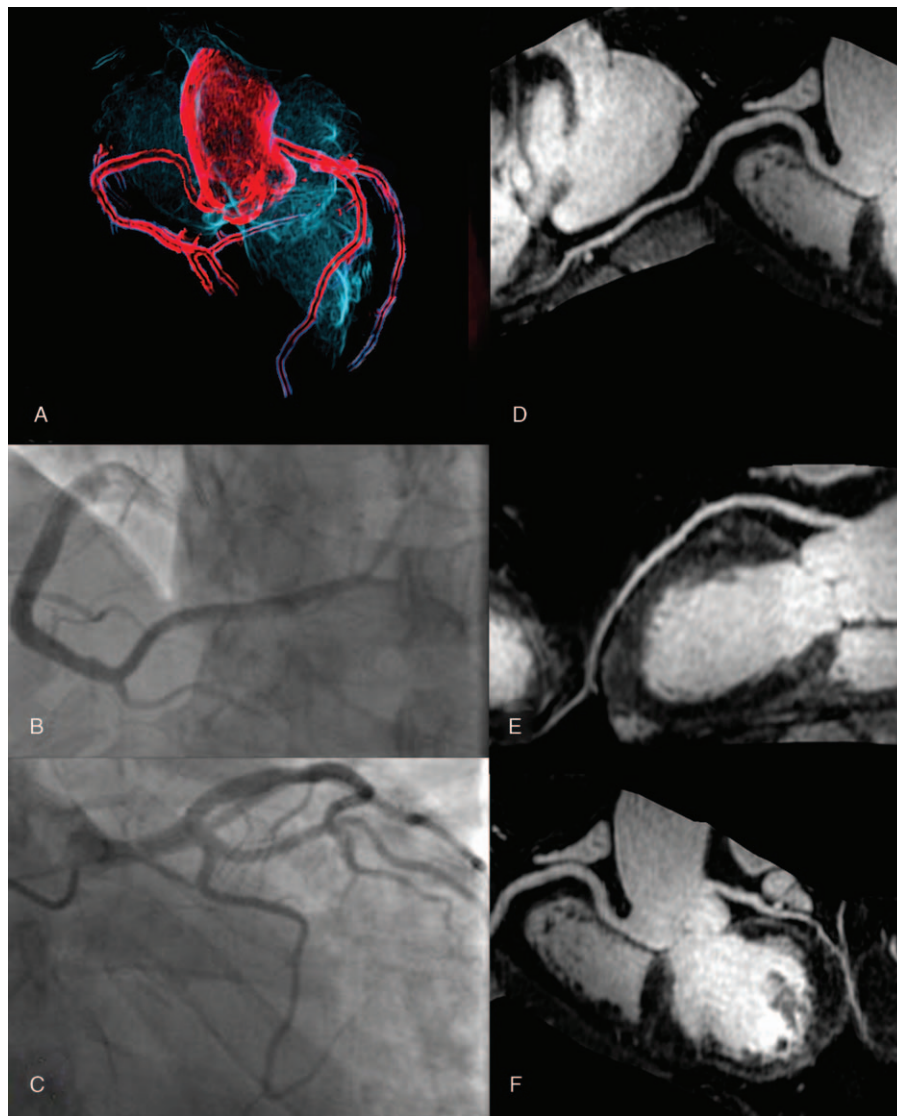


Figure 3. A patient with chronic myocardial infarction shows normal coronary arteries after sublingual nitroglycerin. (A) Volume rendering method shows 3-dimensional view of coronary arteries. (B, C) Conventional coronary angiography reveals normal coronary arteries (D–F) Curved multiplanar reconstruction clearly depicts the right coronary artery (RCA), left anterior descending artery (LAD), and left circumflex artery (LCX).

the combination of such the higher field strength at 3.0T and high-relaxivity contrast agent could yield a significantly higher SNR and CNR, and potentially improve spatial resolution and reduce acquisition time. Second, the 3D approach used to cover whole heart in our study resulted in a higher spatial resolution than the 2D approach. In other words, advantage of the higher spatial resolution is more accurate assessment of transmural extent of infarction of the myocardium. Experiments have already demonstrated that percent transmural enhancement has been shown to be predictive of recovery of regional contraction after revascularization in the setting of chronic MI.^[14,20] Third, free breathing was applied for both two sequences. In particular, the DE-MRI technique in our study were well established because of several advantages, such as independence of the individual breath-hold capability, absence of partial volume effect, and overcoming these drawbacks, which a multislab technique might be overlapped or separated due to different breath-hold positions during acquisition sequences. Therefore, based on several advantages, the MI segments

detected qualitatively on CE-CMRA were highly consistent with that on 3D-PSIR-GRE sequence.

At present, some factors may affect the accuracy of infarct size. First of all, Although CE-CMRA and PSIR could obtain excellent contrast between healthy myocardium and scar tissue, the contrast between blood pool and infarcted myocardium is often unclear, which makes it difficult to give accurate border between the sub-endocardial infarcts and the bright LV blood pool. In order to overcome these drawbacks, Giulia Ginami et al^[21] demonstrated the feasibility of BOOST for simultaneous black-blood LGE assessment and bright-blood coronary angiography. With this technique, Black-blood LGE could improve the contrast between the blood pool and scar tissue. However, the nulling of the blood and viable myocardium signal could not benefit tissue characterization, reducing more accurate delineation of scar tissue. Furthermore, current practice to track the outer contours of the hyperenhanced areas is mostly done manually by 2 experienced reviewers. However, manual depiction of infarction volume is not only time-consuming process that requires skillful

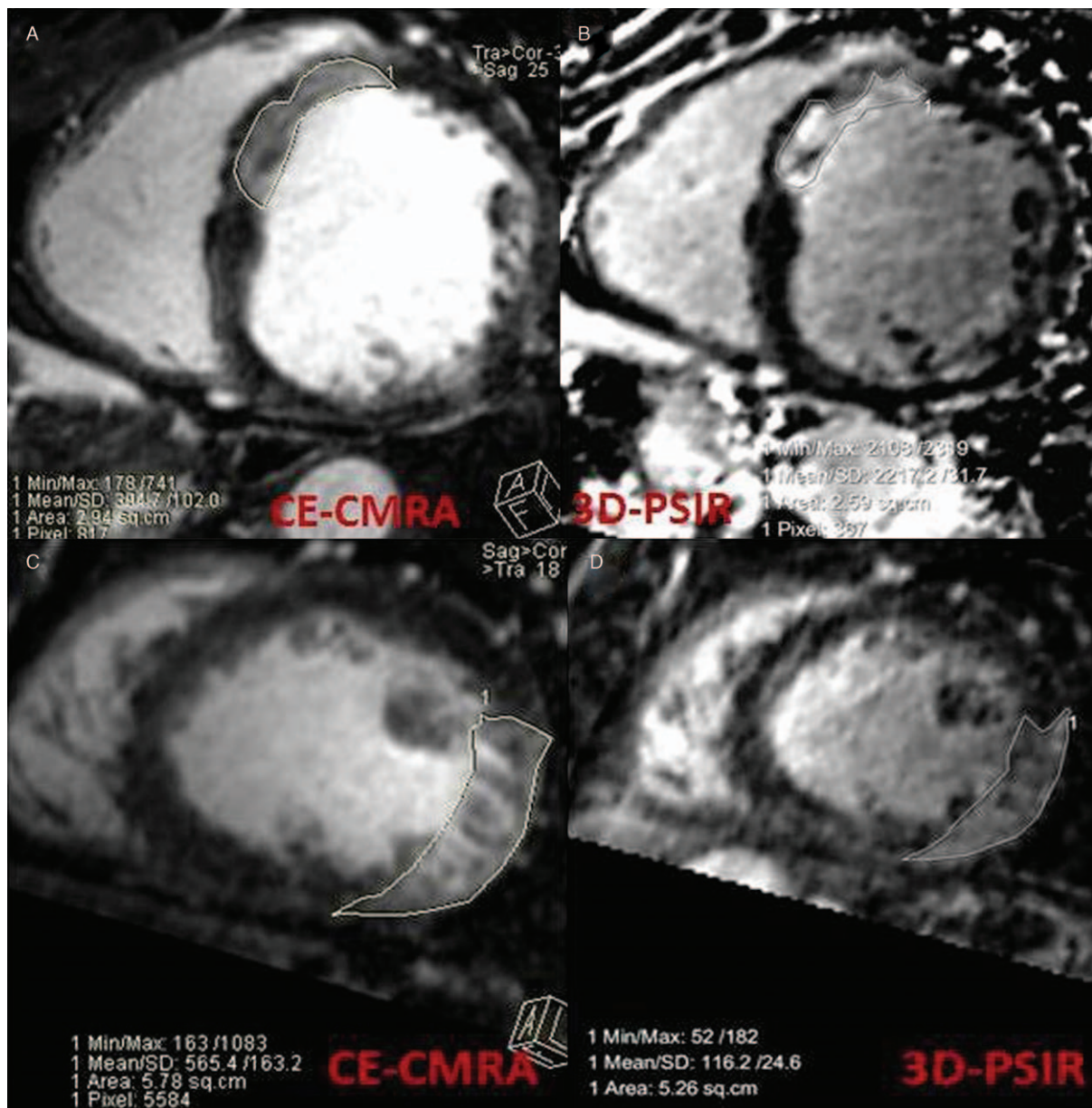


Figure 4. The volume of myocardial infarction assessed between CE-CMRA (A, C) in short-axis orientation and standard 3D-PSIR-GRE sequence (B, D). The single slice areas of myocardial infarction for CE-CMRA are 2.94 and 5.78 cm²; for 3D-PSIR-GRE are 2.59 and 5.26 cm², respectively.

operators, but also prone to resulting in subjective variability. Therefore, it is important to develop computer-assisted algorithm to automatically estimate the size of the LGE, which could contribute to the evaluation process. Recently, several computer-aided methods have been widely exploited in medical image analysis. For instance, Kong et al. proposed a novel deep learning architecture called temporal regression network for efficiently recognizing end-diastole and end-systole frames,^[22] and spatially structured network for cancer metastasis detection.^[23] Jun Chen et al^[24] proposed a correlated regression feature learning for automated right ventricle segmentation.

Invasive coronary angiography is currently the “gold standard” investigation to detect obstructive coronary artery lesions but carries a small risk of serious complications.^[25] Multidetector computed tomography (MDCT) has recently emerged as a promising modality for noninvasive coronary imaging. Meta-

analyses of 64-slice MDCT studies arrived at sensitivities of 93% and specificity of 96%^[26] (in 6 studies) and sensitivities of 86% and specificity of 96%^[27] (in 19 studies). On the other hand, CE-MDCT can characterize acute and chronic MI with contrast patterns similar to CE-MR.^[28] However, coronary CTA requires intravenous injection of iodinated contrast media and exposes the patient to radiation.

4.1. Study limitations

There are several limitations that need to be acknowledged in this study. First, the study population was small. In addition, it is probably high positive rate in patients with myocardial infarction. However, the CE-CMRA technique’s value is focused on the assessment of MI sizes. Second, Relative to invasive angiography as well as coronary CTA, the spatial resolution of

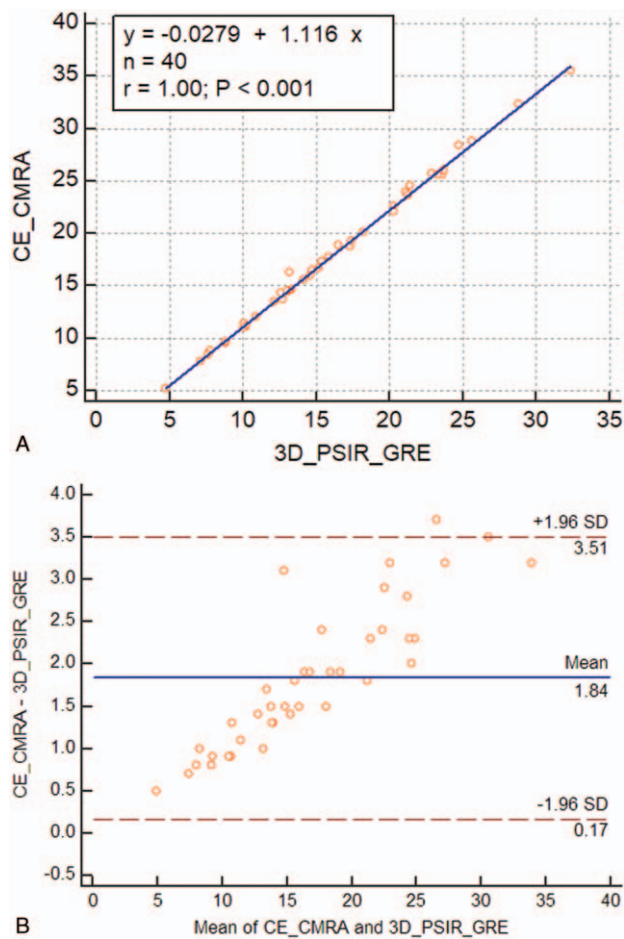


Figure 5. Bland-Altman (B) and regression analyses (A) comparing infarct size between CE-CMRA (contrast-enhanced coronary magnetic resonance angiography) and 3D-PSIR-GRE (phase-sensitive inversion-recovery gradient-echo).

MRA is significantly lower, and the imaging time is still long. Third, the heart commonly moves by the diaphragm in vertical direction. However, some of cardiac insufficiency patients result in shift of the heart in several directions, including vertical and frontal axis, which negatively affect the quality of the examination. Finally, the mean MI volume of nonenhanced myocardium in infarct segments detected on CE -CMRA might significantly increase from the acute to chronic state.

5. Conclusions

In conclusion, CE-CMRA may provide sufficiently high sensitivity and NPV to rule out significant stenosis in patients with chronic myocardial infarction, and could identify and quantify the volume of myocardial infarction, which showed a significant increase of 11.4%, compared with the referenced 3D-PSIR-GRE sequence. Despite this limitation, it is a potential alternative to evaluate myocardial viability because of noncooperation to undergo a prolonged examination instead of DE-MRI in the clinical practice.

Author contributions

Data curation: Lianglong Chen.

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