Radiology

Diagnostic Accuracy of 1.5-T Unenhanced Whole-Heart Coronary MR Angiography Performed with 32-Channel Cardiac Coils: Initial Single-Center Experience[1]

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Purpose: To compare the imaging time and image quality obtained with whole-heart coronary magnetic resonance (MR) angiography performed with five- and 32-channel coils in healthy subjects and determine the accuracy of MR angiography performed with 32-channel coils in the detection of obstructive coronary artery disease (CAD).

Materials and Methods: The institutional review board approved the study protocol, and all participants provided written informed consent. The authors studied 10 healthy subjects and 67 patients suspected of having CAD who were scheduled for coronary angiography. Unenhanced 1.5-T coronary MR angiography was performed with five- and 32-channel coils in healthy subjects and with 32-channel coils in patients. Clinically significant CAD was defined as a diameter reduction of at least 50% at coronary angiography. The sensitivity and specificity of coronary MR angiography were calculated.

Results: The mean imaging time was substantially reduced from 12.3 minutes ± 4.2 (standard deviation) with five-channel coils to 6.3 minutes ± 2.2 with 32-channel coils, with equivalent image quality scores. Acquisition of MR angiograms was completed in all 67 patients, with a mean imaging time of 6.2 minutes ± 2.8. The prevalence of CAD in the study population was 58% (39 of the 67 patients). The areas under the receiver operating characteristic curves as determined at vessel- and patient-based analyses were 0.91 and 0.90, respectively; the sensitivity and specificity at vessel-based analysis were 86% and 93%, respectively.

Conclusion: Whole-heart coronary MR angiography performed at 1.5 T with 32-channel coils permits noninvasive detection of CAD with substantially reduced imaging time. This noninvasive approach can be an alternative to multidetector computed tomographic coronary angiography for ruling out obstructive CAD in patients who have a contraindication to contrast material and in young subjects who are at higher risk from ionizing radiation.

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Whole-heart coronary magnetic resonance (MR) angiography at 1.5 T with use of a steady-state free precession sequence was introduced as a method that can provide visualization of coronary arteries without the use of contrast material (1). In single-center studies performed with five-channel cardiac coils, 1.5-T whole-heart coronary MR angiography demonstrated a sensitivity of 78%–82% and a specificity of 91%–96% in the detection of coronary arteries with a luminal narrowing of at least 50% identified at conventional angiography (2–4). A lengthy imaging time, however, has been considered a major disadvantage of whole-heart coronary MR angiography. In addition, coronary MR angiography was not successfully completed in 8%–13% of patients owing to drift of the diaphragm position during the long imaging time (2–4).

Recently, 32-channel cardiac coils were introduced to reduce the imaging time of cardiac imaging (5). Thirty-two-channel cardiac coils have a 4 × 4 × 2 coil configuration, enabling sensitivity-encoding (SENSE) acceleration in any two of three imaging axes (6). However, the value of 32-channel cardiac coils in the detection of clinically significant coronary artery disease (CAD) has not been fully evaluated in patients suspected of having CAD.

Consequently, our study was performed to compare the imaging time and image quality obtained with whole-heart coronary MR angiography performed with five- and 32-channel coils in healthy subjects and determine the accuracy of MR angiography performed with 32-channel coils in the detection of obstructive CAD.

Materials and Methods

Study Populations

This study consisted of two parts. In the first part, we obtained whole-heart coronary MR angiograms in 10 healthy subjects (nine men and one woman; mean age ± standard deviation, 29 years ± 5; age range, 22–36 years) by using 32- and five-channel cardiac coils. In the second part of the study, we prospectively screened 87 consecutive patients suspected of having CAD who presented with chest pain suggestive of newly developed or recurrent coronary artery stenosis and who were scheduled for conventional coronary angiography for inclusion into this study. Twenty patients were excluded on the basis of the following exclusion criteria: two patients had implantable cardiac devices, five had claustrophobia, three had acute coronary syndrome, three had atrial fibrillation, and seven had previously undergone coronary bypass graft surgery (Fig E1 [online]). Thus, the final study group consisted of 67 patients (49 men and 18 women; mean age, 69 years ± 13; age range, 28–86 years) (Table 1). The prevalence of CAD in the study population was 58% (39 of 67 patients). Three patients had previously been treated with coronary stent placement. Coronary MR angiography was performed within 4 weeks before or after conventional coronary angiography. The mean interval between coronary MR angiography and conventional angiography was 9.7 days ± 10.0. The study complied with the Declaration of Helsinki, our institutional review board approved the study protocol, and all participants provided written informed consent to undergo MR angiography.

Acquisition of MR Angiograms

MR angiograms were acquired by using a 1.5-T MR unit (Achieva; Philips Medical Systems, Best, the Netherlands). Images were obtained with five- and 32-channel cardiac coils in the 10 healthy subjects and with 32-channel cardiac coils in the 67 patients suspected of having CAD. Isosorbide dinitrate (5.0 mg) was sublingually administered to all subjects 3 minutes before acquisition of MR angiograms. β-blockers were not used in this study. The abdominal belt was wrapped loosely in all patients to suppress the motion of the diaphragm in relation to breathing. Initial survey images were obtained to determine the

Advances in Knowledge

- High-quality whole-heart coronary MR angiograms can be obtained with a reduced imaging time (6.3 minutes ± 2.2) and a high study success rate (100%)—even in patients with high heart rates—by using 32-channel cardiac coils and a high parallel imaging factor.
- The large area under the receiver operating characteristic curve and high negative predictive value indicate that unenhanced whole-heart coronary MR angiography can be an alternative to multidetector CT coronary angiography for ruling out obstructive coronary artery disease (CAD) in patients with contraindications to contrast material and in young subjects who are at a higher risk from ionizing radiation.

Implication for Patient Care

- Unenhanced whole-heart coronary MR angiography performed with a 32-channel coil permits detection of CAD without the use of ionizing radiation or contrast material.

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Abbreviations:
A_z = area under the ROC curve
CAD = coronary artery disease
CI = confidence interval
NPV = negative predictive value
PPV = positive predictive value
RCA = right coronary artery
ROC = receiver operating characteristic
SENSE = sensitivity encoding

Author contributions:
Guarantors of integrity of entire study, M.N., K.K., H.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; literature research, M.N., S.K., N.I., M. Ishida, M. Ito, H.S.; clinical studies, all authors; statistical analysis, M.N., S.K.; and manuscript editing, M.N., K.K., M. Ito, H.S.

Potential conflicts of interest are listed at the end of this article.

position of the heart and diaphragm. Then, reference images were acquired to evaluate the individual coil sensitivities for parallel imaging acquisition while the patient breathed freely. To monitor motion of the right coronary artery (RCA), transaxial cine MR images were acquired by using a steady-state free precession sequence while the patient breathed freely (2.6/1.3 [repetition time msec/echo time msec]; 60° flip angle; 320 × 320 × 120-mm field of view; 128 × 128 acquisition matrix; 50 cardiac phases; SENSE factor of three; 3.0-second imaging duration). A patient-specific acquisition window was set during either systole or diastole, depending on the phase of minimal motion of the RCA (2,4). Unenhanced whole-heart coronary MR angiograms were acquired under free breathing in three-dimensional transverse imaging planes by using a steady-state free precession sequence with T2 preparation, spectral presaturation inversion recovery fat saturation, and radial k-space sampling (7) (4.6/2.3; 90° flip angle; full Fourier encoding; 20–50 signals acquired per cardiac cycle; navigator gating window of ±2.5 mm; no drift correction; 280 × 280 × 120-mm field of view; 256 × 256 × 80 acquisition matrix; 512 × 512 × 160 reconstruction matrix). In healthy subjects, whole-heart coronary MR angiograms were acquired three times by employing *(a)* five-channel cardiac coils and a SENSE factor of two in the anteroposterior direction, *(b)* 32-channel cardiac coils and a SENSE factor of two in the anteroposterior direction, and *(c)* 32-channel cardiac coils and a SENSE factor of four (2 × 2) in both the anteroposterior and superior-to-inferior directions. The order of the three acquisitions was randomized in each subject. In patients suspected of having CAD, MR angiograms were acquired with 32-channel cardiac coils and a SENSE factor of four (2 × 2) for the acceleration in both anteroposterior and superior-to-inferior directions. A maximum imaging duration of 30 minutes was predefined to terminate acquisition of MR angiograms and classify the study as unsuccessful.

Table 1

Summary of Patient Characteristics

Characteristic	Value
M/F ratio	49/18
Mean age (y)*	69 ± 13 (28–86)
Mean heart rate (beats/min)*	72 ± 10 (44–95)
Mean body mass index (kg/m^2)*	23 ± 3 (15–32)
Previous myocardial infarction	36 (54)
Coronary stent	3 (4)
Risk factors	
Hypertension	42 (63)
Hypercholesterolemia	33 (49)
Diabetes mellitus	19 (28)
Smoking	17 (25)
Family history of CAD	15 (22)
Stenosis at coronary angiography	
One-vessel disease	21 (31)
Two-vessel disease	12 (18)
Three-vessel disease	6 (9)

Note.—Data were obtained in the 67 patients who underwent coronary MR angiography. Except where indicated, data are given as numbers of patients, with percentages in parentheses.

* Data are given as means ± standard deviations; numbers in parentheses are ranges.

Analysis of MR Angiograms

MR images were transferred to a three-dimensional image server (AquariusNET; TeraRecon, San Mateo, Calif). The coronary artery segment model of the American Heart Association was used for the systematic evaluation of the coronary arteries. Two observers (M.N. and S.K., with 5 and 3 years of experience in coronary MR angiography, respectively) evaluated whole-heart coronary MR angiograms by using sliding thin-slab maximum intensity projection. The slab thickness was 4.0 mm, although the observers were allowed to adjust it as needed (8). The observers were blinded to the clinical history and the presence of left ventricular wall motion on transverse cine MR images. The image quality of whole-heart coronary MR angiograms was independently evaluated by using the following scale: 1, not visible; 2, poor (coronary vessel was barely evident or image was noisy); 3, moderate (coronary vessel was visible but diagnostic confidence was low); 4, good (coronary artery was adequately visualized, with diagnostic quality image); and 5, excellent (coronary artery was clearly depicted). Disagreement between the two observers regarding the image quality score was resolved by a consensus reading. Clinically significant narrowing of the coronary arteries (≥50% reduction in diameter) was visually determined by the two observers. All coronary arteries were included for the evaluation, regardless of image quality, to avoid overestimation of the diagnostic accuracy. Each observer independently recorded the presence or absence of significant narrowing to determine the interobserver agreement of binary judgment. Consensus reading was then performed for the segments in which there was disagreement between the two observers. For receiver operating characteristic (ROC) curve analysis, the two observers visually graded the likelihood of coronary artery stenosis on whole-heart coronary MR angiograms according to the following scale: 1, absent; 2, probably absent; 3, possibly present; 4, probably present; and 5, definitely present. Results for the two readers were averaged to generate ROC curves. To evaluate the effect of heart rate on image quality and diagnostic performance, the patients were divided into two groups on the basis of heart rate. The first group included patients with a heart rate of less than 70 beats per minute (n = 26; mean heart rate, 62 beats per minute ± 7.1; range, 44–69 beats per minute), and the second group included patients with a heart rate of at least 70 beats per minute (n = 41; mean heart rate, 79 beats per minute ± 6.1; range, 70–95 beats per minute).

Conventional Coronary Angiography

Conventional coronary angiograms were evaluated by another reviewer (K.K., with 10 years of experience in conventional coronary angiography), who was blinded to the clinical data and findings at MR angiography, by using quantitative coronary angiography software (QAngio XA; Medis, Raleigh, NC). Significant coronary artery stenosis was defined as a luminal diameter reduction of at least 50%. Lesions with a reference diameter of less than 2.0 mm on conventional coronary angiograms were excluded when determining the diagnostic value of coronary MR angiography.

Statistical Analysis

The data were statistically analyzed by using software (SPSS, version 11.5; SPSS, Chicago, Ill). Continuous values are presented as means ± standard deviations. For comparing the imaging time and image quality score obtained with whole-heart coronary MR angiography in the 10 healthy subjects, one-way analysis of variance was used to evaluate the differences between the three acquisition protocols. When a significant difference was found with one-way analysis of variance, post hoc pair-wise comparisons were conducted with the Bonferroni method. Because the image quality scores were skewed variables according to the Shapiro-Wilk test, differences between image quality scores of two groups were tested by using the Mann-Whitney test. The level of agreement between the two raters with respect to the binary judgments of the presence or absence of stenosis was evaluated with a κ value. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy with per-patient, per-vessel, and per-segment analysis were calculated with a 95% confidence interval (CI). The area under the ROC curve (A_z) was calculated to evaluate the diagnostic performance of whole-heart coronary MR angiography. The correlation between image quality score and heart rate, as well as the level of agreement between the two readers with respect to the five-point scale ratings for ROC analysis, were evaluated by using the Spearman rank correlation test. The significance of differences in diagnostic performance between patients with heart rates less than 70 beats per minute and those with heart rates of at least 70 beats per minute was tested by using the χ^2 test for comparisons of cross-tables. $P < .05$ was considered indicative of a statistically significant difference.

Results

Comparison between Five- and 32-Channel Coils in Healthy Subjects

Acquisition of whole-heart coronary MR angiograms was successfully completed in all 10 healthy subjects by using three acquisition protocols (Fig 1). The mean acquisition time of MR angiography was 12.3 minutes ± 4.2 (range, 7.3–20.7 minutes) with five-channel coils and a SENSE factor of two, 11.8 minutes ± 4.8 (range, 5.8–21.5 minutes) with 32-channel coils and a SENSE factor of two, and 6.3 minutes ± 2.2 (range, 3.3–10.5 minutes) with 32-channel coils and a SENSE factor of four. The image acquisition time with 32-channel coils and a SENSE factor of four was significantly shorter than that with five-channel coils and a SENSE factor of two and 32-channel coils and a SENSE factor of two (P = .005 and P = .01, respectively). No significant differences were found in the image quality scores (Table E1 [online]).

Imaging Time and Study Success Rate in Patients Suspected of Having CAD

Acquisition of whole-heart coronary MR angiograms was successfully completed in all 67 patients (100%), with a mean imaging time of 6.2 minutes ± 2.8 (range, 1.2–16.2 minutes). Whole-heart coronary MR angiograms were acquired during diastole in 49 patients (mean heart rate, 70 beats per minute ± 10; acquisition window, 84 msec ± 57) and during systole in 18 (mean heart rate, 79 beats per minute ± 9; acquisition window, 48 msec ± 18; Fig 2). Table 2 summarizes image quality scores with whole-heart coronary MR angiography for each coronary artery segment. A total of 791 segments were evaluated after exclusion of three segments with stents and 10 segments with a reference diameter of less than 2.0 mm at conventional coronary angiography. No significant differences were found in the image quality scores for any segment between the patients with heart rates of less than 70 beats per minute and those with heart rates of at least 70 beats per minute (P value range, .06–.88). Image quality scores did not show a significant correlation with heart rate (Spearman rank correlation: r = 0.04, P = .16).

Diagnostic Accuracy of Whole-Heart Coronary MR Angiography

At conventional coronary angiography, significant stenoses were revealed in 70 of the 791 segments (9%) in 63 of 201 vessels (31%). With patient-based analysis, the A_z was 0.90 (95% CI: 0.83, 0.98) for the detection of patients having significant CAD (Fig 3). The sensitivity, specificity, PPV, NPV, and accuracy for detecting patients with significant CAD were 87% (95% CI: 72%, 95%), 86% (95% CI: 66%, 95%), 89% (95% CI: 74%, 97%), 83% (95% CI: 64%, 93%), and 87% (95% CI: 78%, 95%), respectively (Table 3). The κ value for the binary judgment was 0.79 (95% CI: 0.64, 0.94), and the Spearman rank correlation coefficient between the two readers was 0.87.

With vessel-based analysis, the A_z for whole-heart coronary MR angiography was 0.91 (95% CI: 0.86, 0.96); the Spearman rank correlation coefficient between the two readers was 0.86. The sensitivity, specificity, PPV, NPV, and accuracy for detecting significant coronary artery stenosis were 86% (95% CI: 74%, 93%), 93% (95% CI: 88%, 97%), 86% (95% CI: 74%, 93%), 93% (95% CI: 88%, 97%), and 91% (95% CI: 87%, 95%), respectively (Table 3). The κ value for the binary judgment was 0.89 (95% CI: 0.83, 0.96). Figure 4 demonstrates the ROC curves obtained with 1.5-T whole-heart coronary MR angiography for three major coronary arteries. The A_z for the RCA, left anterior descending artery (including the left main coronary artery), and left circumflex artery was 0.93 (95% CI: 0.84, 1.00), 0.90 (95% CI: 0.82, 0.98), and 0.90 (95% CI: 0.80, 1.00), respectively. The sensitivity, specificity, PPV, NPV, and accuracy of whole-heart coronary MR angiography in the detection of the left main coronary artery or three-vessel disease were 86% (95% CI: 42%, 99%), 100% (95% CI: 93%, 100%), 100% (95% CI: 52%, 100%), 98% (95% CI: 90%, 100%), and 99% (95% CI: 92%, 100%), respectively (Figs 5, 6). With segment-based analysis, the A_z for whole-heart

Figure 1

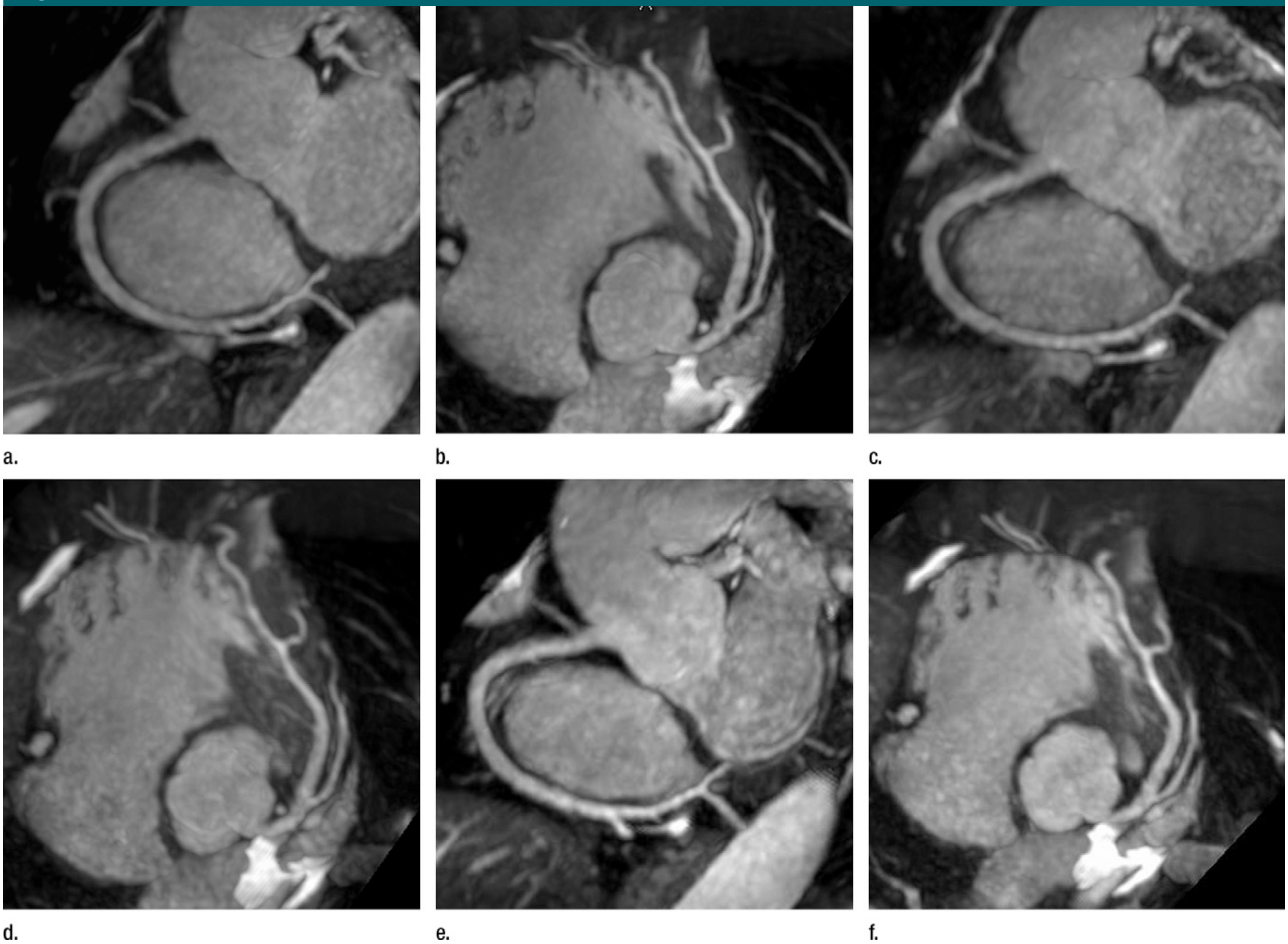


Figure 1: Curved planar reconstruction images from unenhanced 1.5-T whole-heart coronary MR angiography in a healthy subject. Images were obtained with a five-channel cardiac coil and a SENSE factor of two **(a, b)**, a 32-channel coil and a SENSE factor of two **(c, d)**, and a 32-channel coil and a SENSE factor of four **(e, f)**. The RCA is demonstrated in **a**, **c**, and **e**, and the left anterior descending artery is demonstrated in **b**, **d**, and **f**.

coronary MR angiography was 0.92 (95% CI: 0.88, 0.97). Comparison of the two observers' ratings of the likelihood of coronary artery stenosis on coronary MR angiograms is presented in Table E2 (online), and the relationship between the likelihood of stenosis ratings and the presence or absence of significant stenosis at conventional angiography is summarized in Table E3 (online).

Table 4 summarizes the diagnostic performance of whole-heart coronary MR angiography according to heart rate. The sensitivity, specificity, PPV, and NPV obtained at vessel- and segment-based analyses did not significantly differ between the two groups.

Discussion

In the current study, we reported on the first single-center experience of whole-heart coronary MR angiography with use of 32-channel cardiac coils and a SENSE factor of four. Compared with five-channel cardiac coils, 32-channel coils enabled a substantial reduction in imaging time without noticeable worsening of image quality. The vessel-based sensitivity and specificity of whole-heart coronary MR angiography with 32-channel coils in the detection of significant stenoses were 86% and 93%, respectively. The thin-slab maximum intensity projection method was useful for evaluating coronary MR angiograms because pericardial fluid and cardiac veins can be easily differentiated from artery by manipulating the slab along the coronary artery tree.

Contrast material–enhanced multidetector computed tomography (CT) is now widely used as a noninvasive method with which to determine the presence of obstructive CAD (9,10). Coronary MR angiography has several potential advantages compared with multidetector CT (11). First, coronary MR angiography does not expose patients to ionizing radiation. Second, no contrast material injection is required to obtain coronary MR angiograms at a field strength of 1.5 T. Third, the lumen of the coronary artery can be visualized in patients with heavy coronary artery calcification (12).

The acquisition speed of MR angiography, however, is considerably slower than that of recent multidetector CT, making it difficult to obtain whole-heart coronary MR angiograms with sufficient spatial resolution during a single breath hold. Because of this limitation, whole-heart coronary MR angiography has been performed with a free-breathing navigator-echo respiratory gating method, with acquisition times of 10–20 minutes (1–4). The long acquisition time necessary for whole-heart acquisitions results in an increased susceptibility to motion problems (eg, drift of the diaphragm position or heart rate variations during imaging). Consequently, the study success rate of whole-heart coronary MR angiography ranged from 86% to 91% in previous studies using five-channel cardiac coils (2–4). In this study, we used 32-channel cardiac coils to obtain whole-heart coronary MR angiograms with a substantially reduced acquisition time (6.2 minutes ± 2.8); this may explain the high study success rate (100%) observed in our study.

In addition to the benefit of reduced imaging time, 32-channel cardiac coils provide versatility beyond five-channel coils with regard to the setting of acquisition window in the cardiac cycle. In the current study, whole-heart coronary MR angiograms were acquired during diastole and with a mean acquisition window of 84 msec ± 57 in 49 patients and during systole and with a mean acquisition window of 48 msec ± 18 in 18 patients. For comparison, the mean acquisition window in a previous study using five-channel cardiac coils (4) was 152 msec ± 67 for diastolic acquisition and 98 msec ± 26 for systolic acquisition. Improved temporal resolution in the cardiac cycle is important for reducing motion blurring of the coronary artery on whole-heart coronary MR angiograms, especially in patients with a high heart rate.

In the current study, the vessel-based sensitivity and specificity of whole-heart coronary MR angiography were 86% and 93% without excluding segments with poor image quality. These values are somewhat better than those previously reported by Jahnke et al (78% and 91%) (3) and Sakuma et al (78% and 90%) (4), indicating that the use of 32-channel cardiac coils may provide improved diagnostic performance in comparison to five-channel coils, although further multi-institutional study is required to confirm the diagnostic accuracy of this approach.

Whole-heart coronary MR angiography at 3.0 T is another method that has recently emerged to obtain coronary images (13). In a recent study by Yang et al (14), 3.0-T whole-heart coronary MR angiograms were obtained with a mean acquisition time of 9.0 minutes

Table 2

Relationship between Heart Rate and Image Quality Score with Whole-Heart MR Angiography in Patients Suspected of Having CAD

Vessel and Segment*	No. of Segments†	Image Quality Score‡: All Patients (*n* = 67)	Patients with Heart Rate <70 beats/min (*n* = 26)	Patients with Heart Rate ≥70 beats/min (*n* = 41)	*P* Value§
RCA					
1	67	4.8 ± 0.4	4.9 ± 0.3	4.8 ± 0.5	.68
2	66	4.7 ± 0.6	4.8 ± 0.5	4.7 ± 0.6	.72
3	63	4.4 ± 1.0	4.5 ± 1.0	4.4 ± 1.0	.49
4	63	3.5 ± 1.0	3.5 ± 1.0	3.5 ± 1.0	.88
LM					
5	67	4.9 ± 0.4	4.9 ± 0.4	4.9 ± 0.4	.87
LAD					
6	65	4.8 ± 0.5	4.8 ± 0.5	4.8 ± 0.5	.69
7	67	4.5 ± 0.8	4.4 ± 0.7	4.6 ± 0.7	.06
8	67	3.9 ± 0.8	3.9 ± 0.7	4.0 ± 0.8	.48
9	67	3.4 ± 1.0	3.2 ± 0.9	3.5 ± 1.0	.10
LCX					
11	66	4.5 ± 0.8	4.6 ± 0.6	4.4 ± 0.8	.57
12	66	2.8 ± 1.0	2.6 ± 0.9	2.9 ± 1.0	.13
13	67	3.9 ± 1.1	3.9 ± 1.0	4.0 ± 1.1	.39

* LAD = left anterior descending artery, LCX = left circumflex coronary artery, LM = left main coronary artery.

† Three segments with stents and 10 with a reference diameter of less than 2.0 mm at conventional coronary angiography were excluded.

‡ Data are given as means ± standard deviations.

§ *P* values represent the difference in image quality score between patients with a heart rate of less than 70 beats per minute and those with a heart rate of at least 70 beats per minute.

Figure 2

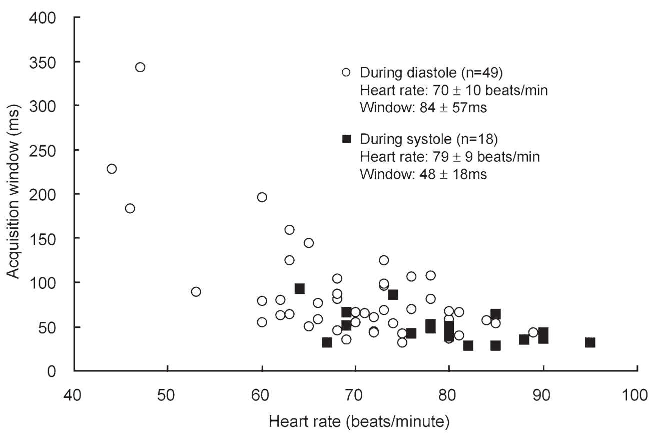


Figure 2: Scatterplot demonstrates the relationship between the patient-specific data acquisition window in the cardiac cycle and heart rate in patients suspected of having CAD.

Table 3

Diagnostic Accuracy of Whole-Heart Coronary MR Angiography

Type of Analysis	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
Per patient (*n* = 67)	87 (34/39) [72, 95]	86 (24/28) [66, 95]	89 (34/38) [74, 97]	83 (24/29) [64, 93]	87 (58/67) [78, 95]
Per vessel (*n* = 201)*	86 (54/63) [74, 93]	93 (129/138) [88, 97]	86 (54/63) [74, 93]	93 (129/138) [88, 97]	91 (183/201) [87, 95]
RCA (*n* = 67)	86 (19/22) [64, 96]	91 (41/45) [78, 97]	83 (19/23) [60, 94]	93 (41/44) [80, 98]	90 (60/67) [82, 97]
LAD (*n* = 67)	87 (26/30) [68, 96]	95 (35/37) [80, 99]	93 (26/28) [75, 99]	90 (35/39) [75, 97]	91 (61/67) [84, 98]
LCX (*n* = 67)	82 (9/11) [48, 97]	95 (53/56) [84, 99]	75 (9/12) [43, 93]	96 (53/55) [86, 99]	93 (62/67) [86, 99]
Per segment (*n* = 791)	83 (58/70) [72, 90]	98 (707/721) [97, 99]	81 (58/72) [69, 89]	98 (707/719) [97, 99]	97 (765/791) [95, 98]

Note.—Numbers in parentheses are raw data; numbers in brackets are 95% CIs.

* LAD = left anterior descending artery, LCX = left circumflex coronary artery.

Figure 3

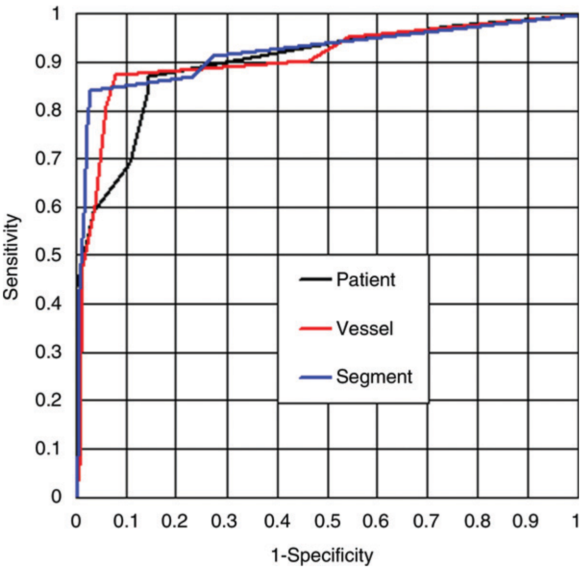


Figure 3: ROC curves for 1.5-T whole-heart coronary MR angiography performed with a 32-channel cardiac coil for detection of significant coronary artery stenosis. The A_z was 0.90 (95% CI: 0.83, 0.98), 0.91 (95% CI: 0.86, 0.96), and 0.92 (95% CI: 0.88, 0.97) with patient-, vessel-, and segment-based analysis, respectively.

Figure 4

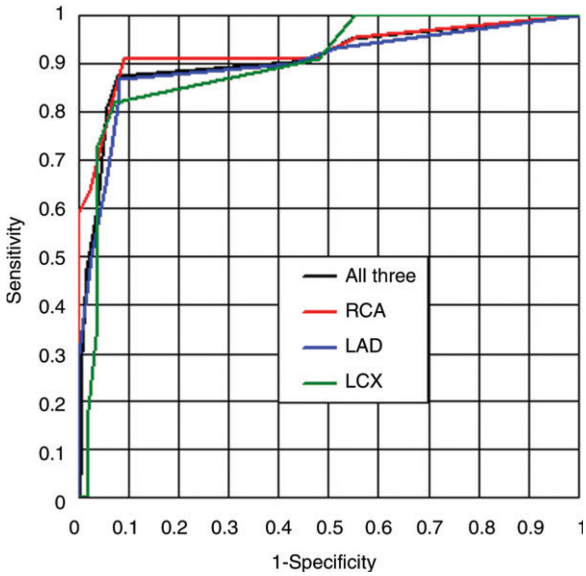


Figure 4: ROC curves for 1.5-T whole-heart coronary MR angiography performed with a 32-channel cardiac coil for vessel detection. The A_z was 0.91 (95% CI: 0.86, 0.96) for all three vessels, 0.93 (95% CI: 0.84, 1.00) for RCA, 0.90 (95% CI: 0.82, 0.98) for the left anterior descending artery (*LAD*) (including the left main coronary artery), and 0.90 (95% CI: 0.80, 1.00) for the left circumflex artery (*LCX*).

± 1.9 by employing 12-channel coils and a parallel imaging factor of two. At vessel-based analysis, they found a sensitivity of 93% and a specificity of 89%. Although 3.0-T contrast-enhanced MR angiography is very promising, 3.0-T whole-heart coronary MR angiography relies on gradient-echo sequences and a double-dose infusion of a high-relaxivity contrast material. The use of contrast material increases study cost and is associated with a potential risk of nephrogenic systemic fibrosis in patients with impaired renal function. Therefore, unenhanced 1.5-T steady-state free precession MR angiography has its own advantages in comparison with 3.0-T contrast-enhanced MR angiography.

Our study has several limitations that should be acknowledged. First, this study was performed as a single-center study with a relatively limited number of healthy subjects and patients. In addition, the mean age of the healthy subjects was 29 years, whereas that of patients was 69 years. The accuracy of 1.5-T whole-heart coronary MR angiography performed with 32-channel coils should be investigated in a multicenter study. Second, the diagnostic accuracy of whole-heart coronary MR angiography performed with 32-channel coils was not directly compared to that with five-channel coils. Third, our study was performed in a patient group with a high prevalence of CAD (58%) because patients who were scheduled for elective conventional coronary angiography were recruited. The findings in this study may not be extrapolated to the

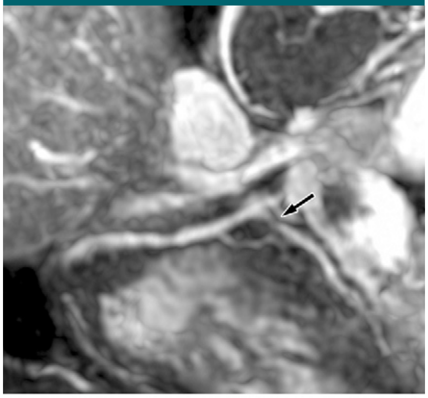
Table 4

Effect of Heart Rate on the Diagnostic Performance of Whole-Heart Coronary MR Angiography

Heart Rate and Analysis	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
<70 beats/min					
Vessel-based analysis (n = 78)	86 (25/29) [67, 95]	96 (47/49) [85, 99]	93 (25/27) [74, 99]	92 (47/51) [80, 97]	92 (72/78) [86, 98]
Segment-based analysis (n = 309)	84 (27/32) [66, 94]	97 (270/277) [95, 99]	79 (27/34) [62, 91]	98 (270/275) [96, 99]	96 (297/309) [94, 98]
≥70 beats/min					
Vessel-based analysis (n = 123)	85 (29/34) [68, 94]	92 (82/89) [84, 97]	81 (29/36) [63, 91]	94 (82/87) [86, 98]	90 (111/123) [85, 95]
Segment-based analysis (n = 482)	82 (31/38) [65, 92]	98 (437/444) [97, 99]	82 (31/38) [65, 92]	98 (437/444) [97, 99]	97 (468/482) [96, 99]

Note.—Numbers in parentheses are raw data; numbers in brackets are 95% CIs.

Figure 5

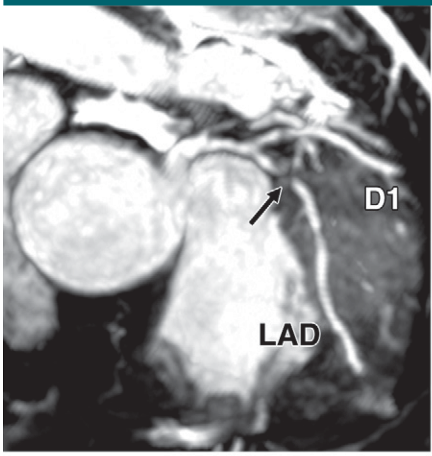


a.

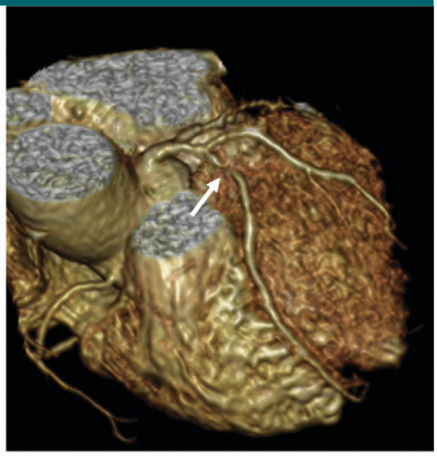
b.

Figure 5: Images in a 78-year-old female patient with chest pain. **(a)** Sliding thin-slab maximum intensity projection image from whole-heart coronary MR angiography and **(b)** conventional angiogram reveal significant stenosis (arrow) in the posterior descending artery of the RCA.

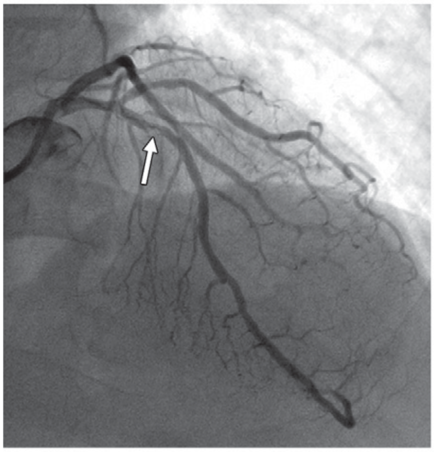
Figure 6



a.



b.



c.

Figure 6: Images in a 50-year-old male patient with chest pain on effort. **(a)** Thin-slab maximum intensity projection image, **(b)** volume-rendered image, and **(c)** conventional angiogram show significant stenosis (arrow) in the proximal portion of the left anterior descending artery (*LAD*). *D1* = first diagonal branch.

population with a lower prevalence of CAD and do not indicate the value of whole-heart coronary MR angiography in the detection of CAD in subjects with low pretest probability. Because PPV, NPV, and accuracy may vary with prevalence, their estimates and CIs are applicable only to a population with the same prevalence. Fourth, lesions with a reference diameter of less than 2.0 mm on conventional coronary angiograms were excluded when determining the diagnostic value of coronary MR angiography. Although diagonal and marginal branches were included for image analyses, the diagnostic accuracy of MR angiography was not determined in these branch vessels with small diameters.

In conclusion, whole-heart coronary MR angiography performed at 1.5 T with 32-channel coils permits noninvasive detection of CAD with a substantially reduced imaging time; the high diagnostic accuracy and high study success rate observed in this study indicate that this approach can be an alternative to multidetector CT coronary angiography for ruling out obstructive CAD in patients with contraindications to contrast material and in young subjects who are at a higher risk from ionizing radiation.

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