

Accuracy of MR coronary angiography in the evaluation of coronary artery stenosis

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PURPOSE

To examine the accuracy of magnetic resonance (MR) coronary angiography for the evaluation of coronary artery stenoses, and to compare the results with conventional angiography as the reference standard.

MATERIALS AND METHODS

Eighteen patients were examined. The pulse sequence was an ECG-triggered, T2-prepared, fat-suppressed 3D true fast imaging with steady state precession sequence with navigator respiratory gating. No contrast material was used. The 3D slabs were oriented axially, covering the whole heart. The MR images were evaluated for the presence of stenoses exceeding 50% luminal narrowing. The diagnostic accuracy of MR angiography was calculated, and was compared with conventional coronary angiography. All patients gave informed consent, and the study was approved by the institutional ethics committee.

RESULTS

In conventional angiography, 16 stenoses were detected in 11 patients, and 7 patients were normal. The sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of MR coronary angiography for detecting coronary stenosis on segment-based analysis were 75%, 98%, 80%, 97%, and 96%, respectively. McNemar test demonstrated no significant difference between MR and conventional angiography ($P = 0.62$).

CONCLUSION

MR coronary angiography is a non-invasive diagnostic method currently in a state of evolution. It has limitations, but can be regarded as an alternative non-invasive modality to detect coronary artery disease in selected patient in whom invasive angiography may be hazardous.

Key words: • cardiac magnetic resonance imaging
• coronary artery stenosis • magnetic resonance angiography

Coronary artery disease is a leading cause of death in most developed countries. The gold standard and the most utilized method to assess coronary artery disease is conventional coronary angiography (1). Conventional angiography has some important advantages over other imaging modalities, such as high spatial resolution (0.2 mm) and high temporal resolution (approximately 8 ms). In addition, therapeutic interventions can be performed in the same session (1, 2).

Conventional angiography is an expensive and invasive procedure, which uses iodinated contrast agents and ionizing radiation. It carries the risk of some rare but severe adverse effects (total complication rate, 1.8%; mortality rate, 0.1%) (1–3). Furthermore, almost 20% of all diagnostic conventional angiographic examinations reveal normal results; only one third are performed in conjunction with an interventional therapeutic procedure (1–3). Therefore, several techniques for noninvasive or less invasive detection of coronary artery disease are being researched. Such techniques could be used to screen or select patients for coronary artery catheterization; this would substantially reduce the number of unnecessary diagnostic catheterizations, and thus would be cost-effective (4, 5).

Over the past decade, coronary magnetic resonance (MR) angiography and multidetector-row computed tomography (MDCT) angiography have emerged as possible alternative noninvasive coronary artery imaging techniques (4, 5).

CT angiography is fast, non-invasive, and easy to perform (5). Previous studies have shown that coronary MDCT angiography has very high diagnostic accuracy in the detection of significant coronary artery stenosis. Therefore, coronary CT angiography has become a routine clinical test; mainly to rule out significant coronary stenosis (5–7). However, CT angiography shares some important disadvantages with conventional angiography, such as the use of ionizing radiation and iodinated contrast material. In addition, severe coronary calcification may reduce the specificity of coronary MDCT angiography for the detection of significant stenoses in patients with high calcium scores (5–7).

Since the late 1980s, several groups have investigated the use of MR imaging for depiction of the coronary artery anatomy and coronary artery stenoses (8–11). MR imaging is a non-invasive method with no inherent major risks; it does not require ionizing radiation or contrast agents. Therefore, it is not harmful to the patient, and can be easily repeated when necessary (12). Because of these advantages, it may be the method of choice in certain groups of patients such as pregnant women, children, and patients with renal insufficiency or allergy to iodinated contrast material (12, 13).

MR imaging of the coronary arteries remains a major challenge because of the small diameter and tortuous course of the coronary arteries, and

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respiratory and cardiac motion (12, 13). To overcome these disadvantages, faster pulse sequences, dedicated cardiac receiver coils, and cardiac and respiratory triggering techniques have been developed and are still evolving (12, 13).

Tremendous progress has been made since the first clinical reports of coronary MR angiography were published in 1991 (8). Current methods for coronary MR angiography combine ECG gating with fast imaging sequences. Also employed are techniques for suppression of signal from surrounding epicardial fat, and suppression of artifacts related to respiratory motion (14–18).

The greatest body of clinical investigations has been performed with segmented gradient echo sequences, described in humans by Edelman et al. (8). In comparison with 2D methods, 3D scanning can reduce partial volume effects and vessel misregistration. Respiratory gating will permit imaging without patient breath-holding. Also, 3D methods offer favourable signal-to-noise ratios and also are well-suited for navigator approaches (19–21). Therefore, 3D scanning is the method of choice. Navigator echo is a motion-compensation technique in which MR imaging data are accepted for image reconstruction only when navigator echo indicates that the diaphragm is within a certain operator-defined range (10, 14, 20, 21).

The aim of this study was to evaluate the efficiency of MR coronary angiography using an ECG-triggered, T2-prepared, fat-suppressed, 3D true fast imaging with steady state precession (FISP) sequence with navigator respiratory gating in demonstrating coronary artery disease and to compare the results with those of conventional x-ray coronary angiography.

Materials and methods

Patient population

In this prospective study, 18 patients who had undergone conventional coronary angiography within 48 hours of MR examinations were included in the study group. In all patients there was clinical suspicion of coronary artery disease (e.g., history of stable angina pectoris or positive stress test results). Thirteen patients were male, and 5 patients were female; mean age was 56.3 years (range, 46–71).

All patients were given detailed information before the examination, and

informed consent was obtained. The institutional ethics committee approved the study.

Exclusion criteria were intracranial vascular clips, indwelling pacemakers, severe claustrophobia, unstable clinical status, history of coronary artery bypass grafting, and history of coronary artery stenting. We excluded patients with previous coronary artery bypass graft placement and coronary artery stent implantation because these might lead to severe susceptibility artifacts, which may make these segments uninterpretable.

MR angiography scan protocol and data analysis

All MR examinations were performed using a 1.5T MR scanner (Avanto, Siemens AG Medical Solutions, Erlangen, Germany).

To achieve optimal image quality in patients with heart rates exceeding 70 bpm, intravenous beta blocker was administered (i.v. metoprolol 5–20 mg) prior to scanning. In our study group, among 18 patients, 11 patients had pre-scan heart rates ≤ 70 bpm. Five of these patients were already receiving beta blocker treatment. Intravenous metoprolol was administered to the remaining 7 patients, whose heart rates were maintained below 70 bpm.

The pulse sequence was an ECG-triggered, T2-prepared, fat-suppressed, 3D true FISP sequence with navigator respiratory gating. The sequence parameters for 3D acquisition were as follows: TR/TE/Flip angle, 277ms/1.6ms/90°; Field of view (FOV), 320 mm; rectangular field of view (RFOV), 75% (iPAT factor 2). FOV was the size of the spatial encoding area of the image. RFOV refers to the smaller FOV in frequency-encoding and phase-encoding directions corresponding to the data acquisition with fewer measurement lines; this was used to decrease the scan time. Slice thickness was 0.8 mm after the interpolation. The voxel size was 1.4 x 1.3 x 0.8 mm, and the matrix was 256 x 230. Patients were examined in supine position. No contrast material was used.

The 3D slabs were oriented axially starting at the aortic root, covering the origins of left and right coronary arteries, and covering the entire left ventricle. Images were obtained using ECG R-wave triggering, and triggering delay was adjusted according to the

heart rate of the patient. In this way, data could be obtained in mid-diastole when there is minimal cardiac motion and maximal coronary blood flow (12, 13).

Respiratory triggering was performed with the navigator echo technique, in which the echo window is positioned above the right diaphragm. Using a navigator echo pulse described as “pencil beam”, small focal areas on the diaphragm are excited, and the position of the diaphragm is detected during scanning. Information regarding motion of the diaphragm is used to set the criteria for accepting or rejecting scan data; only the data acquired in a certain diaphragmatic position are used for image reconstruction (14–16). This technique obviates the need for patient breath-holding. Slice misregistration artifacts due to the variability between held breaths are thus minimized, and patient cooperation is not obligatory. Because many data are rejected, acquisition times are increased, depending on the patient’s breathing pattern (14–16).

The average scan time for the 3D true FISP pulse sequence was 13 minutes (range, 10–24 min). The scan time was shortest in a patient with a regular breathing pattern and cardiac rhythm, and longest in a patient with severe respiratory pattern irregularity.

The delay time (trigger delay) and the acquisition window were automatically adjusted by the scanner, according to the heart rate of the patient.

Data sets were processed on an external workstation (Leonardo, Siemens AG Medical Solutions, Erlangen, Germany) with multiplanar reformation (MPR) and maximum intensity projection (MIP) techniques.

Evaluation of the results of the MR coronary angiography was accomplished by two experienced radiologists (D.Ö. and G.Ö., with 9 and 6 years of MR angiography experience, respectively). Both evaluators were unaware of the results of the conventional coronary angiography. Both source axial and postprocessed MPR images were evaluated in combination with MIP images. Disagreements were resolved by consensus.

The segmental evaluation of the coronary arteries was performed according to the American Heart Association (AHA) classification, which defines 15 segments. Coronary artery

segments that were not visible at MR coronary angiography were excluded from analysis.

Focal areas of decreased luminal diameter, or marked intraluminal signal attenuation or loss were defined as stenoses, while loss of continuity of the vessel segment with no distal luminal signal was considered to be total occlusion. The degree of stenosis was assessed using luminal diameter measurements, as is done in conventional angiography.

Conventional coronary angiography-reference standard

Conventional coronary angiography was performed using standard techniques. Images were obtained of each coronary artery in multiple views. These were analysed by a cardiologist (I.T., with 5 years of angiography experience) who was blinded to the MR angiography findings. The severity of coronary artery stenosis was expressed as percentage reduction in the luminal diameter, determined by using the quantitative coronary analysis method. From these results, only hemodynamically significant lesions (>50% of luminal diameter) were considered.

Statistical analysis

Statistical analysis was performed using a statistical software (SPSS 12.0 for Windows, SPSS Incorporation, Chicago, Illinois, USA).

The diagnostic performance of MR coronary angiography to detect significant stenoses was evaluated. Sensitivity, specificity, positive predictive values (PPV), and negative predictive values (NPV) were presented. These diagnostic parameters were expressed with a 95% confidence interval (CI) calculated with binomial expansion. Conventional coronary angiography was the reference standard.

McNemar test was used to search for a statistically significant difference between MR angiography and conventional coronary angiography to detect significant coronary stenosis. A *P* value <0.05 was considered to be statistically significant.

Results

Conventional coronary angiography

All patients underwent conventional coronary angiography following 1–2 days of MR angiography examinations. By conventional coronary an-

giography, 7 patients were found to have normal coronary arteries with no significant stenosis. In 11 patients, 16 hemodynamically significant stenoses were demonstrated. Conventional angiography revealed one-vessel disease in 5 patients, two-vessel disease in 4 patients, and three-vessel disease in one patient.

MR coronary angiography

MR coronary angiography was well tolerated by all 18 patients. The mean heart rate during the scan was 62 ± 10 bpm. No severe arrhythmia occurred during the scans.

Coronary artery segments that were not visible on MR coronary angiography were excluded from analysis. A total of 94 segments were excluded (35% of vessel segments). These were mainly the distal segments of the vessels, mostly left circumflex (LCX) and right coronary artery (RCA).

In MR angiography, 12 of the 16 significant stenosis were depicted correctly (Figs. 1, 2). Four stenoses were misdiagnosed as normal (false negative) while 3 normal vessel segments were misdiagnosed as stenoses (false positive). Two of the false-negative stenoses were located at the LCX artery, one at the mid-segment, and one at the distal segment. One false-negative stenosis was located at the distal RCA; the other was at the mid-segment of first diagonal branch of left anterior descending artery (LAD). Two of the false positive results were located at the proximal portion of LCX, and one was at distal RCA.

In our study, the sensitivity of MR angiography for the detection of significant coronary artery stenosis on segment-based analysis was 75% (95% CI, 50–88), the specificity was 98% (95% CI, 82–100), the PPV was 80% (95% CI, 58–93), the NPV was 97% (95% CI, 83–100), and the accuracy was 96% (95% CI, 83–100). The McNemar test demonstrated no significant difference between MR angiography and conventional angiography for the detection of significant coronary artery stenosis (*P* = 0.62). This *P* value demonstrated high accuracy of MR angiography for the vessel segments that were eligible for evaluation, but some limitations of the technique should also be addressed, such as high number of vessel segments excluded due to inadequate image quality.

Discussion

In the present study, we used a 3D true FISP MR coronary angiography technique with a real-time navigator to evaluate the presence of significant coronary artery stenoses in a group of patients in whom there was clinical suspicion of coronary artery disease. In our study, the larger, proximal ends of the coronary arteries were better visualised than were the smaller, distal ends, as was true in several previous studies (15, 16, 18, 20, 22). In addition, the real-time navigator technique is optimized to depict this part of the coronary artery tree (16). In our series, the vessel that was most optimally demonstrated was the LAD, and the percentage of cases showing LAD lesions was higher than the percentages of cases with lesions of the other major epicardial vessels.

In general, more blurring was noticed in the distal right atrioventricular groove of the RCA. Distal portions of LCX were minimally visible. The reasons for the poorer visualisation of these parts of the coronary artery system may be related to navigator problems, the length of time required for image acquisition, complex coronary artery motion patterns, tortuosity of the vessels, partial volume artifacts, and superimposition of neighbouring anatomical structures. One of the major problems with LCX was the small vessel diameter; most of the patients had right-dominant coronary circulation (14/18, 77%) similar to what is observed in the general population. In most of the cases, side branches of LCX and LAD could not be clearly demonstrated, mainly due to small calibre of these vessels. The use of contrast agents, particularly intravascular agents, may allow better visualisation of distal coronary arterial segments by using 3D true FISP sequence.

Although a mean percentage of visualisation of 65% of all segments might be disappointing, this finding in the present study is similar to findings in previously published studies (14–18, 23) and this is the main limitation of the technique so far.

Another important problem is the lack of predictability of the image quality. There was extensive variation among patients, and between the right and left coronary artery systems. Some patients who were considered good candidates for MR coronary angiogra-

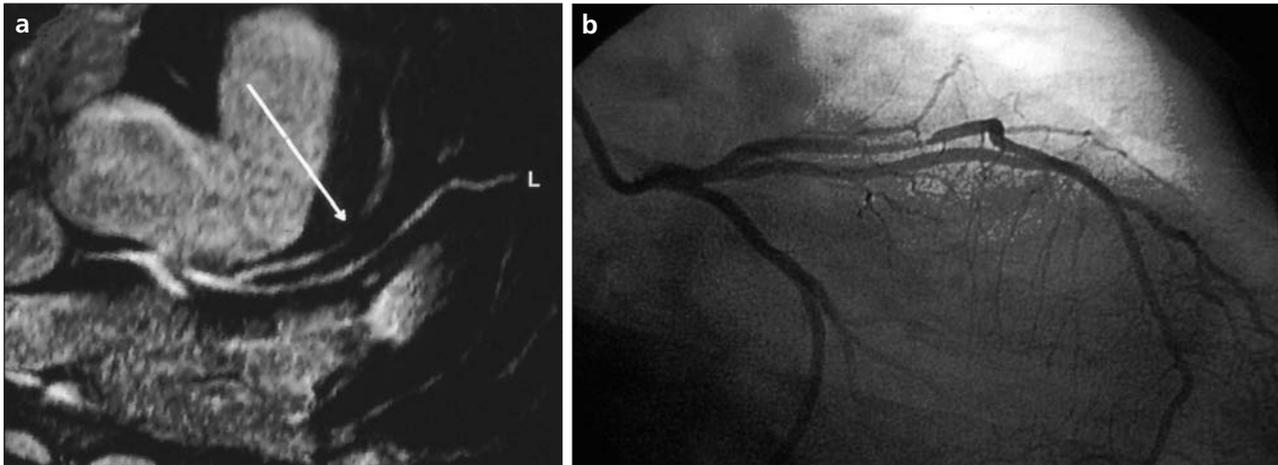


Figure 1. a, b. A 64-year-old male patient with significant stenosis in the proximal segment of left anterior descending artery (LAD). The mean heart rate during the scan was 68 bpm. Axial maximum intensity projection (MIP) MR image (a) demonstrates loss of signal in the lumen of LAD (arrow) with normal distal flow corresponding to the high grade stenosis. Right anterior oblique conventional coronary angiography image of LAD (b) confirms significant stenosis.

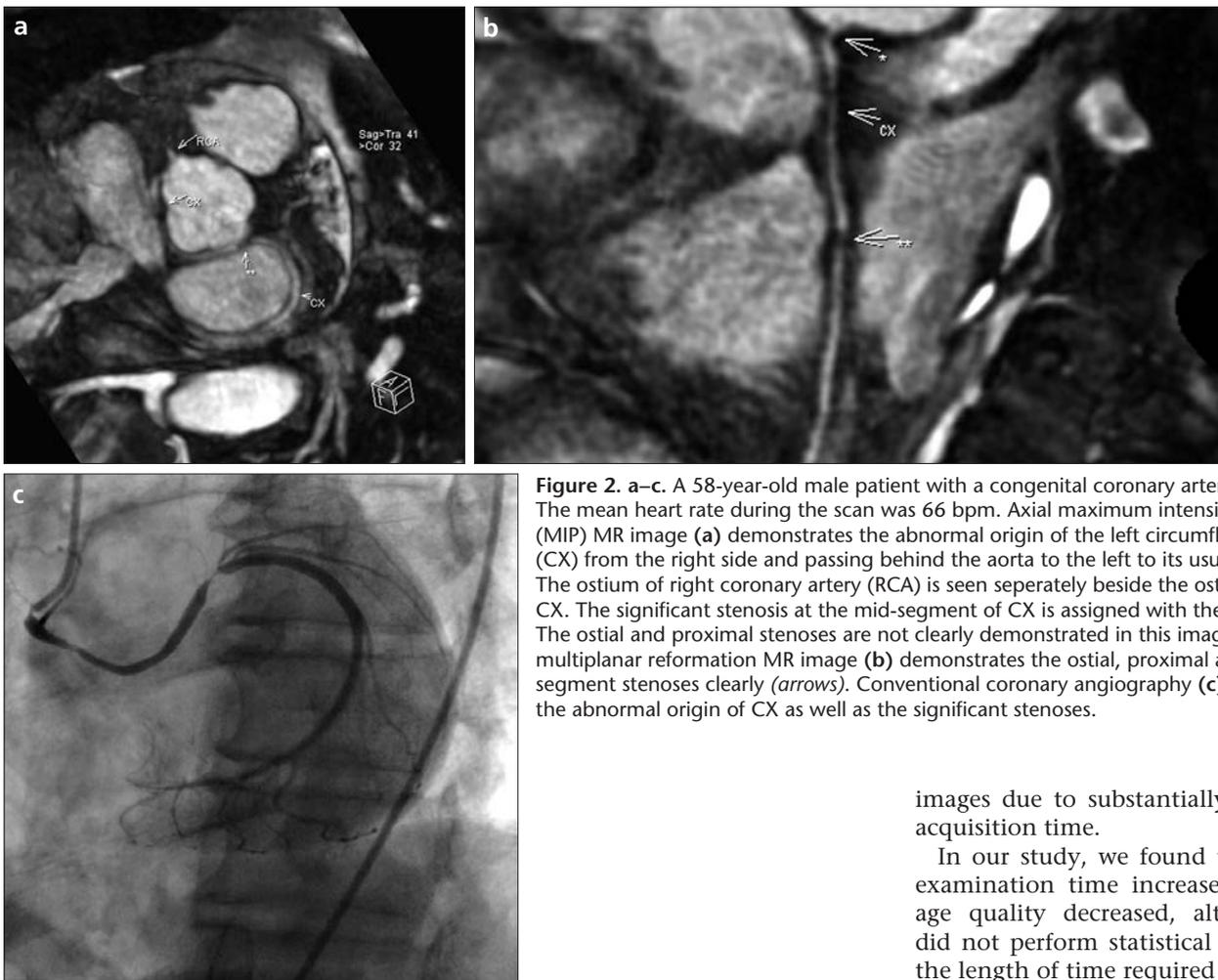


Figure 2. a–c. A 58-year-old male patient with a congenital coronary artery anomaly. The mean heart rate during the scan was 66 bpm. Axial maximum intensity projection (MIP) MR image (a) demonstrates the abnormal origin of the left circumflex artery (CX) from the right side and passing behind the aorta to the left to its usual route. The ostium of right coronary artery (RCA) is seen separately beside the ostium of CX. The significant stenosis at the mid-segment of CX is assigned with the stars. The ostial and proximal stenoses are not clearly demonstrated in this image. Curved multiplanar reformation MR image (b) demonstrates the ostial, proximal and mid-segment stenoses clearly (arrows). Conventional coronary angiography (c) confirms the abnormal origin of CX as well as the significant stenoses.

phy had poor image quality, whereas some who were considered poor candidates had good image quality. Potential explanations for these results include irregularities in heart rhythm or

breathing pattern, and technical issues such as those related to the navigator technique. The ECG or navigator irregularities substantially decreased the image quality and caused blurring of

images due to substantially increased acquisition time.

In our study, we found that as the examination time increased, the image quality decreased, although we did not perform statistical analysis of the length of time required for the MR coronary angiographic examination. Theoretically, administration of a beta blocker may prolong the imaging time by increasing the heartbeat intervals. However, it also allows a longer time for data acquisition per heartbeat, and thus, would tend to shorten the total

duration of imaging. In addition, beta blocker administration also decreases arrhythmia, thus improving the image quality. Therefore, we recommend the routine use of beta blockers for coronary MR angiography.

In our series, two of the lesions with false-negative MR angiography readings were located in the LCX artery, one was in the RCA, and the other was in the first diagonal branch of the LAD. Two of the false positive readings were of lesions in the LCX, and one was in the RCA. The reason for misdiagnosis in all cases was insufficient spatial resolution, mainly due to the small diameter of the coronary vessel segment where the lesion existed. Also, in those cases, the image quality was degraded due to the increased scan time resulting from ECG and/or navigator irregularities.

Additional sources of errors in interpretation include insufficient epicardial fat, partial volume artifacts, and tortuous course of vessels. In the case of insufficient epicardial fat, it may be difficult to differentiate the coronary arteries from the adjacent tissues, which creates a problem, especially on MIP images. Variations in signal intensity due to the changing in-plane and through-plane orientation of the coronary arteries within the 3D slab may mimic vessel stenosis (12, 15, 16, 18). Interpretation of source images along with post-processed images may help to solve these problems (15, 16, 18).

In occluded vessels, flow signal is absent distal to the occlusion, whereas vessels with significant stenoses demonstrate signal loss with distal flow (14–16). However, with complete occlusion of a coronary artery, strong collateral or reverse flow may lead to the misdiagnosis of a complete occlusion as vessel stenosis or even as a normal vessel. Conversely, weak forward flow distal to a stenosis may lead to overestimation of stenosis as occlusion (14–16, 23). In our series, we did not encounter total occlusion, nor did we diagnose a high grade stenosis as occlusion. Because true FISP is not a flow-dependent imaging technique, we did not face problems resulting from flow related artifacts.

Thrombus and some atherosclerotic plaques may contain lipid and/or hemorrhage which may demonstrate high signal intensity on the bright blood technique, and may result in underestimation of the luminal stenosis. We

did not observe such a problem in our series.

There were several limitations to this study. First, the number of patients included in our study was small; a larger study cohort is necessary to assess the diagnostic value of coronary MR angiography for the detection of significant coronary stenosis. Second, due to limited spatial resolution, coronary MR angiography does not allow the detection of stenoses in distal segments and side branches; thus, only lesions located in the proximal and middle segments were assessed in our study. Third, the degree of stenosis depicted on conventional coronary angiograms was assessed by using quantitative coronary artery analysis; however, visual grading was used to assess MR coronary angiographic images. At present, the spatial resolution at MR coronary angiography is suboptimal for precise determination of the degree of arterial stenosis.

In summary, despite substantial technical improvements in MR technology, 3D MR coronary angiography is not sufficiently well developed for the detection of significant coronary artery stenoses in the clinical setting. Image quality is not consistently reliable, the overall image quality is inadequate in some patients, and the distal coronary artery segments may not be visualised. However, MR coronary angiography is effective for the detection of significant stenosis in the proximal segments of coronary arteries. Also, in several published studies, MR imaging was helpful in the interpretation of coronary stenosis in severely calcified segments, in which CT angiography can be misleading or insufficient (22, 24, 25).

MR coronary angiography may be useful for the exclusion of significant coronary artery disease in certain patients in whom invasive coronary angiography and CT coronary angiography may be hazardous. Because it uses neither radiation nor iodinated contrast material, coronary MR angiography can be used to evaluate suspected coronary artery disease in pregnant women, in children, and in patients with renal insufficiency or history of allergy to iodinated contrast material.

In conclusion, coronary MR angiography is a non-invasive diagnostic method currently in a state of rapid evolution. If the necessary technical

improvements can be achieved and the results are confirmed using large patient samples, MR angiography will become the method of choice to detect coronary artery disease in selected patient groups.

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