Coronary Imaging With Cardiovascular Magnetic Resonance: Current State of the Art

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Abstract
Cardiovascular magnetic resonance allows noninvasive and radiation-free visualization of both the coronary arteries and veins, with the advantage of an integrated assessment of cardiac function, viability, perfusion, and anatomy. This combined approach provides valuable integrated information for patients with coronary artery disease and patients undergoing cardiac resynchronization therapy. Moreover, magnetic resonance offers the possibility of coronary vessel wall imaging, therefore assessing the anatomy and pathology of the normal and diseased coronary vessels noninvasively.

Coronary magnetic resonance angiography is challenging because of cardiac and respiratory motion and the small size and tortuous path of the coronary vessels. Several technical solutions have been developed to optimize the acquisition protocol to the specific clinical question. The aims of this review are to provide an update on current technical improvements in coronary magnetic resonance angiography, including how to optimize the acquisition protocols, and to give an overview of its current clinical application. (Prog Cardiovasc Dis 2011;54:240-252) © 2011 Elsevier Inc. All rights reserved.

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Despite substantial improvements in prevention and treatment,¹ coronary artery disease (CAD) remains the leading cause of death and disability in the Western world.² The current criterion standard for the diagnosis of CAD is cardiac catheterization. In the United States alone, 16,300,000 patients have CAD and approximately 1,000,000 cardiac catheterizations are performed each year.² In up to 40% of examined patients, no significant coronary artery stenoses are diagnosed.³ Therefore, a noninvasive test that could directly assess the integrity of the coronary lumen would be desirable.⁴ Cardiovascular magnetic resonance (CMR) allows a comprehensive evaluation of myocardial function, perfusion, and morphology in patients with CAD.⁵ In addition, magnetic resonance angiography (MRA) can be used for direct visualization of the coronary artery lumen, whereas black-blood techniques allow the visualization of the coronary vessel wall,⁶ making CMR a tool capable to provide all required diagnostic information in one single examination.

Moreover, the same MRA techniques allow the visualization of the anatomy of the coronary veins, which is of interest for the optimal placement of pacemaker leads in cardiac resynchronization therapy.⁷,⁸ This review provides an update on current improvements in coronary MRA and an overview on its current clinical use.
Technical challenges and general imaging strategies for coronary CMR

Coronary MRA demands dedicated techniques to optimize image contrast and ensure a high signal-to-noise ratio (SNR) yielding a clear delineation of blood-filled structures or the vessel walls with high spatial resolution. Because high spatial resolution is required for adequate visualization of the coronary vessels, the concomitant intrinsic cardiac and respiratory motion poses a major challenge to coronary MRA and vessel wall imaging.

To overcome this, a standard coronary MRA protocol comprises (1) electrocardiogram (ECG) triggering for synchronization of the heart motion with the data acquisition, (2) respiratory navigation for synchronization/compen-sation of the respiratory motion, (3) prepulses to modify the magnetization (spin preparation) and ensure sufficient image contrast, and (4) the imaging sequence itself (Fig 1).

Compensation of cardiac motion: ECG triggering

To freeze cardiac motion, data acquisition has to be synchronized with the cardiac cycle and to be limited to periods of minimal cardiac movement.9 Resting periods occur in end-systole (approximately 280-350 milliseconds after the R wave) and in mid-diastole (immediately before atrial systole). Both acquisition strategies (systolic or diastolic) have advantages and disadvantages (Table 1).

The optimal trigger delay and the length of the acquisition window depends on the patients’ heart rate, the type of imaging sequence used, the structure to visualize (arteries vs veins), and other hemodynamic factors. Although the use of a heart rate–dependent formula to identify the mid-diastolic resting period is effective in many subjects, there may be considerable intersubject variation.10 Therefore, the resting period should be identified for each patient from a free-breathing high–temporal resolution cine scan in the 4-chamber view performed shortly before the coronary scan.9 Real-time arrhythmia rejection to exclude irregular heartbeats may further improve coronary MRA image quality.11-14

Another important parameter to consider is the duration of the resting period. It is typically longer for the left compared with the right coronary artery system. Thus the length of the acquisition window of a whole-heart acquisition is determined by the duration of right coronary artery diastasis.

Compensation of respiratory motion: navigator

The displacement of the heart due to respiration can exceed 2 to 3 cm, requiring synchronization of image acquisition with the respiratory cycle. High-resolution 3-dimensional (3D) data sets are not compatible with breath-hold acquisitions. Several approaches have been tested to reduce the effect of respiratory motion on image quality. Prospective real-time navigator gating and correction techniques are the current approach to minimize respiratory motion artifacts.15,16 A pencil beam 1-dimensional navigator typically positioned on the dome of the right hemidiaphragm is used to monitor the foot head motion17 of the diaphragm immediately before coronary image acquisition (Fig 2). Depending on the position of the diaphragm, the data are either accepted when the position falls within a certain acceptance window (usually 3-5 mm) or rejected. In the latter case, the data have to be remeasured in the subsequent cardiac cycle.

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Reduction of the acceptance window reduces the motion artifacts but increases the overall acquisition time because more data are rejected. An acceptance window of 5 mm usually allows an efficiency approaching 50%.18-20

To increase the percentage of accepted data, the position of the imaging slice can be prospectively adapted to the measured respiratory position. Normally, the movement of the heart due to breathing is less pronounced than the motion of the diaphragm itself; and a scale factor between 0.4 and 0.6 has been used for optimal slice tracking. However, also with the use of these techniques, respiratory-induced motion of the heart often cannot be completely modeled by a simple translation along the foothead direction; and it has been shown that in up to 30% of patients, an affine transformation models the respiratory motion more accurately.21,22

Other proposed approaches include the use of image-based navigators that directly track cardiac motion, navigators that monitor the movement of the epicardial fat,23 scanning in prone position,24,25 and the use of an abdominal or thoracic banding.25,26

**Coronary artery imaging**

**Sequences**

Three-dimensional approaches require long acquisition times and were initially not feasible. The first approaches to coronary artery angiography were attempted by Edelman et al22 and Manning et al27 by 2-dimensional (2D) gradient-echo techniques. One slice was acquired in 16 heartbeats (in a single breath-hold), and patients were free to breath between acquisitions. The introduction of navigator techniques allowed the acquisition of data in free breathing, and 3D techniques became feasible. These sequences can be acquired using a whole-heart or target-volume approach (Table 2).

**Table 2**

<table>
<thead>
<tr>
<th>Whole-Heart Imaging</th>
<th>Target-Volume Imaging</th>
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<tbody>
<tr>
<td>Axial-, sagittal-, or coronal-oriented imaging volume</td>
<td>Right and left coronaries are imaged in 2 individually planned thin slabs</td>
</tr>
<tr>
<td>Planning on set of axial, sagittal, and coronal scout images to include the entire heart</td>
<td>Quicker planning performed on a low-resolution free-breathing coronary scout scan</td>
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<tr>
<td>Preferably isotropic spatial resolution to allow for 3D reformatting along the course of the coronary vessels</td>
<td>The central slice is defined by selection of 3 points located on the path of the coronary vessel</td>
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<tr>
<td>Full coverage (simultaneous acquisition of the venous system)</td>
<td>Targeted coverage</td>
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<tr>
<td>Long acquisition time</td>
<td>Shorter acquisition time than whole-heart approach</td>
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<tr>
<td>Limited in-flow effect (less contrast, particularly in gradient echo techniques)</td>
<td>Noninotropic voxels with in-plane spatial resolution of $1 \times 1$ mm$^2$ and slice thickness of $2-3$ mm</td>
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Two different approaches are currently in use: the whole-heart and the vessel-targeted approach, which requires an individual planning procedure. Whole-heart techniques have been also used for coronary vein imaging.36,59
**Contrast-enhancing spin preparations**

The use of 3D acquisitions has the advantage of improved SNR and higher spatial resolution but also has the disadvantage of reduced contrast between blood and the myocardium (less in-flow effects). Therefore, contrast-enhancing spin preparations techniques in combination with steady-state free-precession (SSFP) techniques have been developed to provide sufficient contrast for the delineation of the coronary arteries. Steady-state free-precession sequences are currently preferred to T1-weighted gradient echo sequences on 1.5-T systems because of the higher intrinsic SNR and the better contrast between blood and myocardium. However, SSFP sequences have limitations at 3 T due to longer repetition times (more stringent specific adsorption rate model) and thus increased sensitivity to off-resonance and the need for higher flip angles to obtain enough contrast between blood and myocardium. At 3 T and higher field strengths, gradient echo techniques appear as promising alternative to SSFP techniques.

For non-contrast agent–enhanced imaging, spin preparation usually includes fat suppression and T2 preparation. Frequency selective prepulses can be applied to saturate the signal from fat tissue, allowing the visualization of the coronaries. To enhance the contrast between the coronary lumen and the underlying myocardium, T2 preparation techniques can be used to suppress signal from myocardium, as blood and myocardium have similar T1 but different T2 (Fig 3).

T2 preparation also suppresses deoxygenated venous blood and therefore is not suited for coronary vein imaging. A few other techniques to improve contrast between the vessel lumen and the myocardium have been proposed but are not widely adopted. Among these are spin-locking and magnetization transfer techniques. Magnetization transfer preparation does not affect the signal from deoxygenated venous blood and can therefore be used to image the coronary veins. Further improvement of contrast between blood and the surrounding tissues can be achieved by application of contrast agents.

**Contrast agents**

Extracellular, blood-pool, and contrast agents with weak albumin binding have been used to improve contrast-to-noise and image quality of coronary MRA. As coronary artery imaging protocols should ideally become part of a routine ischemia/CAD diagnostic imaging protocol, the choice of the contrast agent depends on a balance between increasing contrast between lumen and myocardium while maintaining the ability to provide useful scar information in late gadolinium enhancement images. Extracellular contrast agents allow limited coronary artery enhancement because of the rapid extravasation in the interstitial space. Blood-pool contrast agents offer the highest contrast between the vessel lumen and the surrounding tissues but may face limitations for late enhancement imaging. Contrast agents with weak albumin-binding appear most promising for combined coronary artery and infarct imaging because of their prolonged retention time in blood and their higher relaxivities (useful to improve image quality of coronary MRA), while maintaining good late enhancement properties.

To take advantage of contrast agents for coronary MRA, a saturation or inversion prepulse is usually applied instead of T2 preparation. The rapid T1 recovery of blood after contrast agent administration (native T1 of blood = 1200 milliseconds, T1 of blood with contrast agent = 50-100 milliseconds, native T1 of myocardium = 850 milliseconds) allows the generation of high contrast between the coronary lumen and myocardium.

**Recent improvements in acquisition speed and resolution**

Faster image acquisition can result in better image quality due to reduced sensitivity to motion because of a shorter acquisition window or shorter overall data acquisition time. To accelerate data acquisition and/or reduce motion sensitivity, several approaches have been proposed, such as faster encoding of k-space by use of echo planar imaging or more efficient k-space sampling using spiral or less motion-sensitive k-space sampling using radial trajectories. These techniques...
have not yet become established standards for coronary MRA because of their off-resonance sensitivity (echo planar imaging, spiral) or signal-to-noise penalty (radial).

More recently developed parallel imaging techniques such as sensitivity encoding\(^5\) or simultaneous acquisition of spatial harmonics\(^4\) have been successfully applied to reduce the overall MRA acquisition time while maintaining image quality. With the advent of 2D coil arrays (eg, 32-channel coils), acceleration along the slice encoding and phase encoding direction can be applied, thereby further reducing scan time. However, acceleration factors greater than 4 can hardly be realized because of SNR limitations and increasing reconstruction artifacts.\(^4,5\)

**Coronary vein imaging**

In the past decades, coronary imaging has been mainly focused on the coronary arteries. With the advent of resynchronization devices, the assessment of the course of the coronary veins has become increasingly important and has recently gained interest for preinterventional identification of optimal placement site for the left ventricular lead of resynchronization devices. Three-dimensional MR coronary vein angiograms can be overlaid onto real-time-acquired x-ray images to provide improved guidance for catheter implantation.\(^5,6\)

Because of the low oxygen saturation of coronary venous blood (causing a strong reduction of blood T2 values), T2 preparation is not suitable for coronary vein imaging. Current approaches include non–contrast-enhanced imaging by magnetization transfer preparation\(^3,5\) or using gadolinium contrast, including blood-pool,\(^7,8,5\) extracellular,\(^6\) and contrast agents with weak albumin binding.\(^5\) Of interest is the approach proposed by Duckett et al\(^6\) of slow infusion of a high-relaxivity contrast agent during coronary vein MRA acquisition, which offers the possibility to acquire late gadolinium enhancement images after the redistribution of the contrast agent.

The optimal acquisition window for coronary vein imaging is in end-systole, when the coronary vein diameter is maximal.\(^36\) However, ECG triggering may be difficult in patients with heart failure due to tachycardia, orthopnea, and the asynchronous contraction of the LV, making the resting period different in independent segments of the left ventricular chamber. In these cases, the acquisition parameters should be adapted; and data acquisition in end-diastole might be an alternative (Fig 4).

**Coronary vessel wall imaging**

The excellent soft tissue contrast of magnetic resonance imaging enables the visualization of the vessel wall. First, in vivo images of coronary vessel wall were obtained by 2D fat-saturated fast spin echo techniques.\(^52,63\) For improved contrast between the blood and the vessel wall, a double inversion recovery preparation was applied to obtain black-blood images.\(^64\)

Further developments of the technique combined the double inversion recovery prepulse with fast gradient echo readout techniques\(^55\) and recently with spiral\(^66\) and radial acquisition trajectories.\(^57\) Clinical studies demonstrated outward positive remodeling with relative lumen preservation in patients with established CAD and increased vessel wall thickness in patients with type I diabetes and renal

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![Fig 4](image-url)  
Fig 4. Magnetic resonance angiogram of the coronary veins, obtained using a whole-heart approach and an intravascular contrast agent, adapted from Chiribiri et al.\(^7\) A, B and C: examples showing the wide interindividual variability of the anatomy of the cardiac venous system in terms of presence, relative position, and diameter of the coronary sinus tributaries. The knowledge of the anatomy and variations of the cardiac venous system may facilitate the positioning of the left ventricle lead in patients undergoing cardiac resynchronization therapy. **Abbreviations:** CS = coronary sinus; LA = left atrium; LV = left ventricle; LMV = left marginal vein; PIV = posterior interventricular vein; PVLV = posterior vein of the left ventricle; RA = right atrium; RV = right ventricle; RCA = right coronary artery; SCV = small cardiac vein.
dysfunction. Confirming the findings of previous studies done by using intravascular ultrasound, coronary vessel wall imaging could offer an attractive and noninvasive alternative for the clinical assessment of patients.

For selective imaging of fibrous or inflamed plaque, several preclinical and clinical studies have been performed using delayed gadolinium enhancement techniques, showing promising results. In vivo, clinically approved contrast agents showed nonspecific uptake in plaques both in patients with chronic angina and in patients with acute coronary syndromes (Fig 5). Contrast uptake in patients with stable angina was associated with calcified or mixed plaques on multislice computed tomography (MSCT), whereas contrast uptake in patients with ACS was transient and thus more likely related to inflammation.

In experimental animal models, several target-specific contrast agents have been tested. Accumulation of albumin binding blood-pool contrast agent indicates increased endothelial permeability and/or increased neovascularization. The accumulation of iron oxide particles (ultra-small super paramagnetic iron oxide) indicates increased endothelial permeability and vessel wall inflammation due to the presence of intraplaque macrophages.

Novel molecular contrast agents, which specifically target molecules or cells, have recently been developed that allow selective visualization of inflammatory markers such as intercellular adhesion molecule–1, vascular adhesion molecule-1, or matrix metalloproteinase.

Recent work also includes the specific labeling of thrombi by a fibrin-specific contrast agent. Molecular contrast agent may provide new opportunities for the characterization of early atherosclerotic lesions and for the assessment of plaque vulnerability.

**Special considerations: intracoronary stents**

Coronary stents are currently used in a large number of patients undergoing percutaneous revascularization. Typically made of high-grade stainless steel, coronary stents cause negligible attractive force and local heating both at 1.5 T and 3 T with clinical safety demonstrated for imaging early after implantation at 1.5 T.86-88 A. Chiribiri et al. / Progress in Cardiovascular Diseases 54 (2011) 240–252

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**Fig 5.** Localized uptake of extracellular contrast agent (Gd-DTPA) in unstable CAD, adapted from Ibrahim et al. Right coronary artery from a subject with unstable angina. A, Image fusion between coronary MRA (B) and delayed-enhancement (DE)-MRI (C) that shows significantly enhanced vessel wall signal. D, Comparison with x-ray angiography.
In the United States, both the Cypher (Cordis, Miami Lakes, FL) and Taxus Liberte (Boston Scientific, Natick, MA) drug-eluting stents are approved for CMR scanning immediately after implantation. However, coronary stents cause local susceptibility artifacts and signal voids that preclude the assessment of persistent and intrastent coronary integrity.

Clinical applications

The application of MRA is currently limited to the assessment of anomalies of the coronary arteries (class I indication) and aortocoronary bypass grafts (class II indication). The use of MRA for the assessment of native coronary arteries has not yet become clinically routine.87

**Coronary artery angiography for the detection of CAD**

Proximal and medial segments of the main branches of the coronary arteries can routinely be visualized by free-breathing navigator-gated fast gradient echo or SSFP techniques. Especially the proximal segments are evaluable in nearly 100% of subjects. The left anterior descending and the right coronary arteries are usually imaged with better image quality than the left circumflex coronary artery that runs in the direct vicinity of the myocardium and at a larger distance from the coil elements. The mean length of the vessels that were visible in previous studies was approximately 50 mm for the left anterior descending coronary artery, 80 mm for the right coronary artery, and 40 mm for the left circumflex coronary artery,27,28,73,88-92 with an excellent agreement between the proximal vessel diameters between MRA and conventional angiography.93 However, despite the most recent technical developments, spatial resolution of coronary MRA is still lower than that of invasive coronary angiography, limiting the size of the branches that can be assessed. Despite these limitations, coronary artery stenosis in proximal segments can often be identified by coronary MRA. On “bright blood” (gradient echo/SSFP) images, a stenosis appears as a signal void in the otherwise bright vessel (Fig 6). This is primarily due to the reduction of the lumen and partly due to the presence of turbulence of the blood flow distal to the stenosis that may result in a dephasing of the signal and thus lead to an overestimation of the severity of the stenosis with MRA when compared with invasive angiography.94

An international multicenter study4 assessing the diagnostic accuracy of coronary MRA revealed a high sensitivity (92%) and a low specificity (59%) for the detection of CAD. The relatively limited spatial resolution of coronary MRA contributed to these results, as demonstrated by the excellent performance observed for the exclusion of left main or 3-vessel disease (sensitivity, 100%; negative predictive value [NPV], 100%). These results have been confirmed in a series of smaller single-center studies, with good results for the detection of significant coronary stenosis in the proximal coronary segments.26,28,95-102

Coronary MRA has recently been proposed in conjunction with late gadolinium enhancement to rule out ischemic etiology in patients presenting with dilated cardiomyopathy without symptoms of myocardial infarction.87 A recent meta-analysis compared coronary MRA and MSCT for ruling out significant CAD in adults.103 The conclusion was that MSCT is more accurate than MRA and that, therefore, MSCT should be considered as the preferred noninvasive alternative method to coronary catheterization to exclude CAD. However, the added value of a coronary MRA scan integrated into a comprehensive clinical protocol encompassing function, structure, perfusion, and viability scans still needs to be assessed and has the potential to provide a more accurate evaluation of patients with known or suspected CAD. A more recent national multicenter study

![Fig 6. A, Coronary artery stenosis visualized on white blood MRA images. B, Comparison with coronary artery angiography. Visualization of multiple stenoses and wall irregularities in the proximal RCA.](image-url)
from Japan demonstrated that non–contrast-enhanced whole-heart coronary MRA at 1.5 T can noninvasively detect significant CAD with high sensitivity (88%) and moderate specificity (72%). In the study, an NPV of 88% indicates that whole-heart coronary MRA can rule out CAD. Of note, the NPV of this coronary MRA multicenter trial is identical to the NPV of the Coronary Evaluation Using Multi-detector Spiral Computed Tomography Angiography using 64 Detectors (CORE-64) MSCT multicenter study. Remarkably, the value of coronary MRA in patients with a low pretest likelihood is similar to computed tomography and can reliably rule out CAD in patients with a pretest likelihood of less than 20%.

Coronary anomalies and aneurysms

Anomalies of the origin and path of the coronary arteries and coronary aneurysms are accurately visualized by coronary MRA as a result of their higher caliber and preferred location in proximal or ectatic segments. Coronary MRA has the important added benefit of allowing a noninvasive reliable diagnosis without exposing the patient to ionizing radiation (Fig 7). This is particularly important in younger patients and children, as well as in younger women.

Coronary bypass grafts

The visualization of bypass grafts benefits from their rather stationary position, straight and known course, and large diameter as compared with the native coronary arteries. Spin echo techniques and gradient echo techniques have been used. Contrast agents have been applied for enhancement of the blood signal, which resulted in sensitivities between 95% and 100%.

A major limitation of bypass imaging results from the presence of metallic clips, which cause signal voids due to susceptibility artifacts. Although coronary MRA has been

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**Fig 7.** Coronary MRA for the visualization of the anomalous origin of the coronary arteries, from Boffano et al. T2-prepared navigator-gated whole-heart technique shows the anomalous origin of a single coronary artery from the right sinus of Valsalva in a patient complaining for angina. A, Maximum intensity projection image demonstrating the anomalous origin of the single coronary artery from the right sinus of Valsalva (white arrows). B, Maximum intensity projection image showing the path of the right coronary artery and of the left coronary artery, crossing in front of the right ventricle outflow tract. C, Volume rendering reconstruction of the heart, showing the anomalous origin of the single coronary artery (*) from the aorta and the course of the RCA and the LCA. D, Coronary angiography in right anterior oblique projection, showing the anomalous coronary tree. Abbreviations: AO = aorta; LCA = left coronary artery; MIP = maximum intensity projection; PA = pulmonary artery; RVOT = right ventricle outflow tract.
used in specialized centers to identify stenosis in the bypass grafts with good accuracy compared with invasive angiography, the presence of metallic clips in the proximity of the bypass grafts and coronary arteries often results in signal voids that prevent a full assessment of the respective anatomy.

**Coronary vessel wall imaging**

By means of black-blood techniques, the latest clinical magnetic resonance imaging scanners can provide a detailed visualization of the coronary artery wall. The major impediment to clinical application of these techniques is the need for very high spatial resolution and the related long acquisition times.

The vessel wall can be visualized either in a cross-sectional view or along the path of the vessel. Because of reduced partial volume effects, the cross-sectional orientation should provide more accurate quantification of the vessel wall thickness but provides limited coverage. A long-axis view of the vessel wall provides a more extensive visualization and typically allows assessment of the proximal 5 cm. The use of contrast agents allows for selective plaque visualization. By using an extracellular contrast agent, delayed enhancement images can show focal or diffuse uptake of contrast agent and enhancement due to the presence of a fibrous plaque or due to inflammation. The current application of coronary vessel wall imaging is restricted to research purposes; but in the future, it may become part of CAD risk assessment and monitoring of treatment response, especially if plaque targeting agents become available.

**Coronary vein imaging**

Imaging of the coronary veins and the integration of coronary vein anatomy and myocardial scar information may help to guide the left ventricular lead implantation to achieve optimal cardiac resynchronization therapy (Fig 8). Early studies have shown that contrast agent–enhanced

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Fig 8. Visualization of coronary veins and scar in a patient referred for cardiac resynchronization therapy. Adapted from Duckett et al. A, Three-dimensional reconstruction of the heart with the coronary venous system. B, Two-chamber late gadolinium enhancement, with scar in the inferior segments of the left ventricle. C, Segmented LV registered to the scar imaging in the short axis view. D, Segmented whole heart with the coronary veins and scar all superimposed. Abbreviation: GCV = great cardiac vein.
CMR can be used for the assessment of the course of the coronary sinus, the great cardiac vein, and the respective tributaries. A major limitation in patients with heart failure may arise from the asynchronous contraction pattern of the left ventricle, causing constant systolic motion of the heart. This may disqualify the suggested use of an end-systolic trigger window, and the use of a mid-diastolic triggering window may be more effective.

Conclusions: future perspective

Although the spatial resolution of coronary MRA for the visualization of the coronary lumen is not as high as for MSCT, novel coronary magnetic resonance imaging techniques have shown potential in providing additional information including plaque burden and biology by black-blood coronary MRI or use of nonspecific and targeted MR contrast agents. Currently, novel contrast agents targeting specific molecules or cells are undergoing preclinical evaluation and some have already been tested in humans. In addition, direct thrombus visualization and assessment of endothelial function and coronary edema have recently been demonstrated.

Finally, ongoing developments in motion compensation techniques will simplify the acquisition of coronary MRA with the advantage of improved image quality and a shorter scan time.

Statement of Conflict of Interest

All authors declare that there are no conflicts of interest.

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