Society for Cardiovascular Magnetic Resonance: Advances in Research and Clinical Applications

Highlights From the 13th Annual SCMR Scientific Sessions, January 21-24, 2010, Phoenix, AZ

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The annual Scientific Sessions of the Society for Cardiovascular Magnetic Resonance (SCMR) is now in its 13th year and has grown significantly both in numbers of attendees, as well as in substantive scientific presentations. This year 439 abstracts were presented in the sessions, along with lectures targeted at general cardiovascular magnetic resonance (CMR), congenital/pediatric applications, and basic CMR science. The meeting was attended by 1170 physicians, technologists, and basic scientists.

Reviewed by Juliano Lara Fernandes, MD, Universidade Estadual de Campinas, São Paulo, Brazil; Gerald M. Pohost, MD, FACC, FAHA, Keck School of Medicine, Viterbi School of Engineering, University of Southern California, and Westside Medical Imaging, Los Angeles, CA.

Highlights of the meeting this year included advances in CMR for both research and clinical applications. The present report is focused on 5 main topics: 1) new imaging methods, 2) myocardial perfusion imaging, 3) late gadolinium enhancement, 4) coronary artery and plaque imaging, and 5) applications to metabolism and spectroscopy. The abstracts discussed can be read online in a recent edition of the *Journal of Cardiovascular Magnetic Resonance*.[1]

New Imaging Methods

The use of higher magnetic fields, with parallel imaging and high-density coils, has been considered among the greatest advances in hardware in recent years.[2] Many presentations at this year's SCMR meeting described new applications of 3T CMR coupled with 32-channel coils to achieve improved spatial resolution, shorter breath-hold durations, or more spatial coverage. These approaches provided substantial improvement in perfusion and coronary artery imaging, but were also applied to increase the speed of the cine MR imaging, as was described by Sandner and colleagues,[3] who described an approach using 5 imaging slices per breath-hold and a 4-fold accelerated cine steady-state free precession (SSFP) technique that compared favorably with unaccelerated sequences. A similar approach was described by Wintersperger and associates,[4] where the total acquisition time in 30 patients was 273 ± 124 seconds versus 34 ± 5 seconds for accelerated SSFP.

Although 3T is gradually replacing lower fields in clinical CMR, this year's SCMR meeting described the application of 7T. The ability to gate using electrocardiography is considerably more difficult at 7T than at lower field strengths (ie, 1.5T and

3T). Frauenrath and coworkers[5] described 7T for the assessment of left ventricular (LV) function using ultrasound tracking of cardiac motion or phonocardiography to allow triggering, obviating the problem of the distorted electrocardiograph at 7T. Van Elderen and coworkers[6] and Agarwal and associates[7] presented results on the use of a 7T commercially built system for 3-dimensional (3D) MR angiography (MRA) to visualize the right coronary artery. Both studies showed that arterial intimal edge sharpness was increased substantially at 7T compared with 3T. Tracking of respiratory motion as a means of reducing chest motion was technically more difficult at 7T.

Another area that appears to be drawing increased attention is the mapping of T_1 and T_2 relaxation parameters. Previous studies have shown that quantitative assessment methods over conventional CMR techniques may allow improvement in specific diagnosis of various diseases affecting the myocardium.[8,9] It is interesting that such parametric mapping is not new. Substantial work was performed in the mid 1980s.[10,11] Piechnik and colleagues[12] showed a new, modified "look locker" inversion recovery sequence that can produce T_1 maps while nearly reducing acquisition time by a factor of 2 compared with the standard T_1 imaging techniques. The clinical application of T_1 mapping was described by Bauner and coauthors,[13] who showed that this approach can differentiate between chronically infarcted and normal myocardium using the LV blood pool as a reference and by Dall'Armellina and associates,[14] who claimed to be able to distinguish between acutely infarcted versus normal myocardium without the use of contrast agents at 3T. Peters and coworkers[15] showed in phantoms that the use of T_1 mapping can be exploited to further refine gray zone characterization using a rather difficult and nonstandardized approach for T_1 mapping by applying conventional threshold qualitative approaches.[16]

Finally, given the concerns regarding nephrogenic systemic fibrosis,[17] more emphasis has been given to CMR approaches without the use of contrast agents, not only for angiography but also for perfusion imaging. The arterial spin labeling (ASL) approach has been shown previously to be capable of detecting differences in myocardial blood flow with limited success.[18,19] Zun and coworkers[20] determined myocardial blood flow in 11 normal subjects with ASL at 3T showing that the technique was able to detect blood flow and that the blood flow and increase of 4.97 $\pm$ 4.6 times the resting flow with adenosine infusion could be demonstrated. French and colleagues[21] developed a gated ASL method in mice that could overcome cardiac and respiratory irregularities. This approach demonstrated an increase in myocardial perfusion after cardioprotective gene therapy that generated extracellular superoxide dismutase.

Recently, in multicenter trials and outcomes studies, CMR perfusion imaging has been shown to be more successful for assessing myocardial perfusion than single-photon emission computed tomography imaging.

Myocardial Perfusion Imaging

The annual audience questionnaire at the SCMR meeting this year indicated that myocardial perfusion imaging was thought to be the most important strategy in CMR, ranking at the top of the list for the approach in most need of further development. Recently, in multicenter trials and outcomes studies, CMR perfusion imaging has been shown to be more successful for assessing myocardial perfusion than single-photon emission computed tomography (CT) imaging.[22,23] Despite this, the acceptance and utilization of the CMR perfusion imaging methods have not increased. Nevertheless, this year great attention was given to perfusion imaging, and among the most significant advances in CMR was the development of a highly accelerated method to improve resultant CMR myocardial perfusion imaging studies. One such study, reported by Otazo and coworkers,[24] used a compressed sensing parallel imaging technique at 3T where the authors obtained high spatial resolution ($<$ 2 mm) and temporal resolution (60 ms/image) with whole heart coverage (10 slices/heartbeat) using an acceleration factor of 8 and a 12-element coil. Similarly, Manka and colleagues[25] studied 20 patients at 3T with suspected coronary artery disease (CAD) and demonstrated the same degree of acceleration using the approach known as k-space and time sensitivity encoding (*k-t* SENSE) with remarkable (in-plane) resolution of 1.13 $\times$ 1.13 mm^2 and temporal resolution of 90 ms. The area under the curve for the detection of stenosis $>$ 50% was 0.94 in images classified as good to excellent during stress. Lockie and coauthors[26] demonstrated that a similar technique with a slightly reduced acceleration factor of 5 led to substantial reduction in problematic dark rim artifacts. Their study demonstrated good interobserver agreement and remarkable reduction of the dark rim artifact, which

had previously been a confounding artifact in perfusion imaging. In addition, Maredia and associates[27] suggested that maximizing spatial resolution using *k-t* SENSE acceleration in place of improving spatial resolution promoted the most reliable imaging of ischemic rim thickness, extent, and duration.

As described previously, there is increasing interest in the use of CMR imaging approaches without the use of contrast agents. Two approaches that are evolving include ASL and blood oxygen level-dependent (BOLD) imaging.[28,29] Arnold and associates[30] used BOLD perfusion imaging to assess myocardial perfusion in 45 patients. Using catheter-based coronary angiography as the standard, sensitivity was 94% and specificity was 61% with a predictive accuracy of 81%. Many studies evaluated the new applications of diagnostic and prognostic clinical CMR data. Pilz and colleagues[31] followed 158 patients with an intermediate to high pretest risk and a normal adenosine stress CMR myocardial perfusion imaging study. The authors showed that the negative predictive value of a normal study was 96.2% in the group without previously documented CAD and 90.7% in patients with previous percutaneous coronary interventions, demonstrating that CMR could be used to exclude unnecessary invasive coronary angiography in the diagnostic evaluation for CAD. Because both CMR perfusion and late gadolinium enhancement (LGE) are generally performed in combination in clinical practice to optimize diagnostic accuracy,[32] Coelho-Filho and coworkers[33] examined the prognostic ability of this combined study. The authors evaluated 473 patients with an intermediate pretest likelihood of CAD followed for 26.4 months and showed that reversible myocardial perfusion as demonstrated by CMR provided a hazard ratio (HR) of 4.2 for major adverse cardiovascular events in age and ejection fraction-adjusted patients. The negative predictive value for death was 99% in the presence of LGE and significant perfusion deficits.

Late Gadolinium Enhancement

The information provided by LGE has increased significantly since the technique was introduced for detection of myocardial infarction (MI) in 2001.[34] Since then, LGE has proven to be a powerful tool for diagnosis, and for risk stratification in many other diseases that affect the myocardium.[35] For diagnosis, new data were presented by Jeanneteau and coworkers[36] in 33 patients with a clinical diagnosis of acute myocarditis. There was a significant inverse correlation between the mass of myocardium that demonstrated LGE and the ejection fraction. Also, Morelos[37] showed that LGE can be useful for detection of myocardial involvement in patients with progressive systemic sclerosis even in the presence of preserved systolic function. In peripartum cardiomyopathy Cannan and associates[38] demonstrated LGE in 50% of a small retrospective series of 14 patients who developed heart failure within 5 months postpartum. They also observed that edema as defined by T2 weighted imaging was more prevalent than LGE with an incidence of 79%.

In a representative study in which LGE played a significant role in risk assessment, Deac and associates[39] found that 22% of patients with LGE in the left ventricle and suspected arrhythmogenic right ventricular dysplasia had major cardiovascular events; this number increased to 26% in patients with LGE in the right ventricle. In hypertrophic cardiomyopathy (HCM), O'Hanlon and colleagues[40] demonstrated that patients with LGE had a worse prognosis. Follow-up after 3.1 ± 1.7 years in 217 patients with HCM showed that 63% of the group with LGE present had an HR for combined cardiovascular outcomes of 3.4 compared with patients with no LGE. In patients with ischemic cardiomyopathy, Larose and coworkers[41] followed 103 patients after acute ST-elevation MI and showed that the volume of myocardium with LGE was the best predictor of late LV dysfunction at 2 years (with an adjusted odds ratio [OR] of 1.36), with an LGE volume > 30% or 18 mL/m^2 with an OR of 10.1 for adverse events.

Although the specificity of LGE was high, its sensitivity for the diagnosis of extensive CAD has not been demonstrated as presented. Wassmuth and coworkers[42] retrospectively studied 554 patients with total coronary occlusion using CMR. The authors found that 8.8% of these patients showed no evidence of LGE and all patients had evidence of coronary collaterals.

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Coronary Artery Lumen and Plaque

Coronary artery imaging is considered one of the most important goals for the future of CMR. New whole-heart 3D coronary artery imaging sequences have become commercially

available on most new scanners, but have not achieved the level available with current radiographic CT technology.[43] Nevertheless, Li and collaborators[44] compared 32 patients with suspected CAD who underwent both whole-heart 3D coronary MRA (3DMRA) at 3T using a 32-channel coil to radiographic CT angiography. These investigators found that, in the 88% (n = 28/32) of technically assessable coronary segments that could be evaluated by CMR, the overall accuracy was superior to that of coronary CT angiography. With similar CMR hardware, Wiethoff and colleagues[45] demonstrated that high-quality, whole-heart, coronary artery imaging could be performed in less than 2 minutes with isotropic resolution of 1.5 mm^3 and an acceleration factor of 4. Bhat and associates[46] reported a newly developed radial echo planar imaging sequence that allowed whole-heart coronary MRA, with $1 \times 1 \times 2$ mm^3 spatial resolution on a 3T scanner. The average acquisition time was 4.9 minutes and image quality was good. Finally, Hauser and coworkers[47] demonstrated that, in patients with reduced ejection fraction of unknown etiology, coronary MRA had a higher accuracy compared with LGE for the correct classification of ischemic versus nonischemic cardiomyopathy.

The previous CMR coronary angiographic approaches used luminography alone. CMR can also characterize plaques reported by Jansen and coauthors.[48] These investigators studied 16 patients following an acute coronary syndrome (ACS) event using T_1-weighted 3D inversion recovery of the coronary artery walls. They used contrast CMR to identify the culprit lesion and found a sensitivity of 85% compared with catheter-based coronary angiography and intravascular ultrasound. Compared with other coronary lesions, culprit lesions demonstrated a 4-fold increase in contrast uptake. In laboratory animals (the apolipoprotein E knockout mouse fed a high-fat diet), Using a fibrin-targeted contrast agent, Makowski and associates[49] demonstrated, that plaque CMR image characteristics (contrast to noise ratio [CNR] and T_1 signal) decreased with statin treatment. The authors concluded that vulnerable plaque could be identified using such contrast agents and allow earlier diagnosis of active CAD. Without the use of contrast agent, Jansen and colleagues[50] used a T_1-weighted 3D inversion recovery black-blood gradient echo pulse sequence and demonstrated intracoronary arterial thrombus in 19 patients with ACS. These authors demonstrated a 9-fold increase in CNR of coronary arterial segments with thrombus compared with segments without thrombus. Sensitivity was 91% and specificity was 100% for correct classification of thrombus-laden segments compared with catheter-based angiography.

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Metabolism and Spectroscopy

The application of CMR spectroscopy (CMRS) and imaging for the evaluation of metabolism continues to improve. Some of the most remarkable advances in CMR have been shown in this area. CMRS requires no contrast agent and stress is frequently induced using nonmagnetic handgrip stress. CMRS uniquely allows assessment of intramyocardial metabolism.[51] Pohost and colleagues[52] studied 45 patients of Latin origin with type 1 diabetes mellitus using 3T ^{31}P spectroscopy with handgrip stress and at rest. The authors found that 13 of the 45 subjects demonstrated significant reduction in phosphocreatine/adenosine triphosphate ratio during stress that was significantly more common in patients with retinopathy, suggesting more advanced microvascular disease. ^{31}P spectroscopy was also used by Suttie and coworkers[53] to identify early myocardial involvement in patients with Becke and Duchenne muscular dystrophy showing that these patients had abnormal cardiac energy metabolism despite normal systolic ventricular function. To allow more widespread clinical use of ^{31}P spectroscopy, Dass and associates[54] used a shorter acquisition protocol using a larger voxel size of 93 mL versus the previous standard of 39 mL in 22 healthy volunteers with a 3T scanner. Derived phosphocreatine/adenosine triphosphate ratios were similar in both groups with a significant reduction in acquisition time (8 min vs 20 min).

A relatively new area of research in CMR, ^{19}F MRI, was a frequently presented topic during the meeting. These presentations spanned applications that allow cell tracking and regional delivery of nanotechnology. Fu and coworkers[55] described the use of ^{19}F MRI to track mesenchymal stem cell delivery in rabbits, whereas Myerson and colleagues[56] showed that perfluorocarbon nanoparticles attached to a specific thrombin inhibitor could be identified and localized using ^{19}F MR spectroscopy. A similar approach by the same group was used to deliver exogenous small interfering RNA to mice endothelial cells and by Zhang and

collaborators[57] to study endothelial dysfunction in rabbits.

Conclusions

This year's SCMR Annual Scientific Sessions demonstrated a growing number of significant developments in CMR, continuing the tradition for this meeting since the establishment of the Society. Despite these advances, there is still a gap between where these applications are today and their use by the practicing physician. When the clinical users realize and apply the underused potential of this remarkable noninvasive technology, a technology method without the need to use ionizing radiation, can be performed repeatedly to follow patients with little risk, and with high spatial and contrast resolution, CMR will displace or replace some of the existing imaging technologies, enhance the information available to the clinician, and reduce the cost of diagnosis in the practice of cardiology, cardiovascular radiology, cardiothoracic surgery, and other related disciplines. ■

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Main Points

- High-field cardiac magnetic resonance (CMR) has become more regularly applied in clinical practice and, along with parallel imaging and high-density coils, has helped the development of new imaging methods.
- Perfusion imaging has improved both in terms of resolution and coverage; new methods, such as blood oxygen level-dependent (BOLD) and arterial spin labeling have allowed for assessment of ischemia without contrast agents.
- Late gadolinium enhancement abstracts were presented with a focus on the significant prognostic information provided in many different cardiomyopathies.
- CMR coronary angiography continues to improve thanks to 3T and 32-channel coils; characterization of plaques with different targeted contrast agents is a future possibility under development.
- Metabolic evaluation by CMR with the use of spectroscopy was highlighted in abstracts that showed its use in hand-grip stress as well as in muscular dystrophies, with new ^{19}F MR on the horizon.

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