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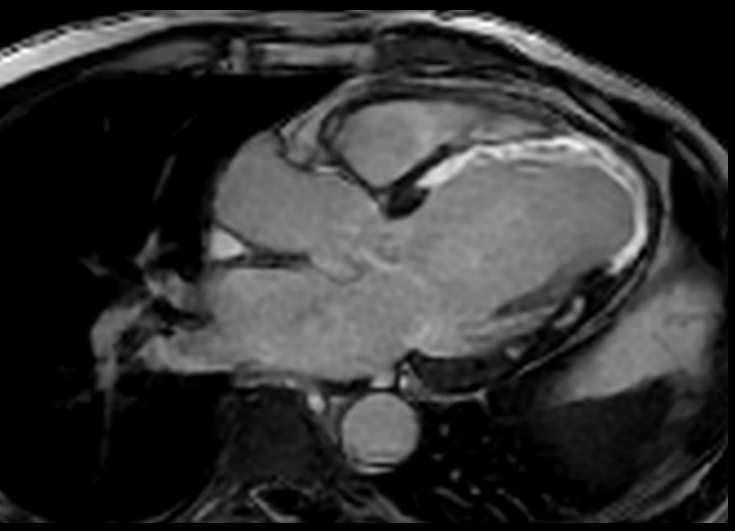

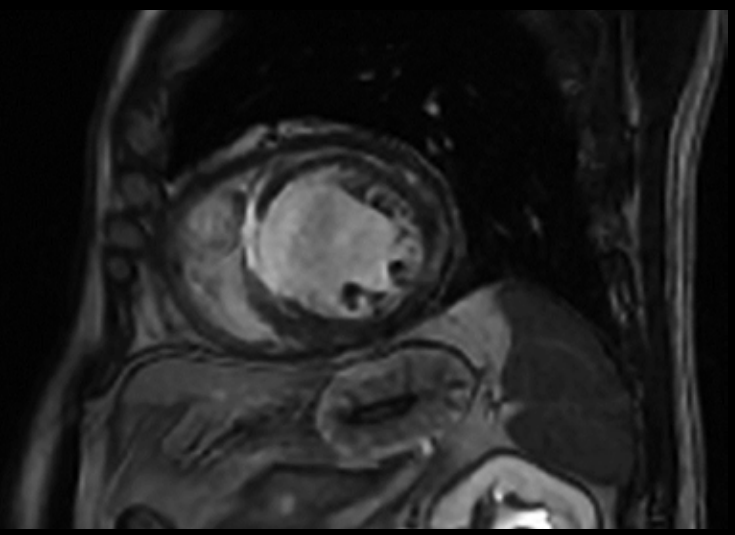

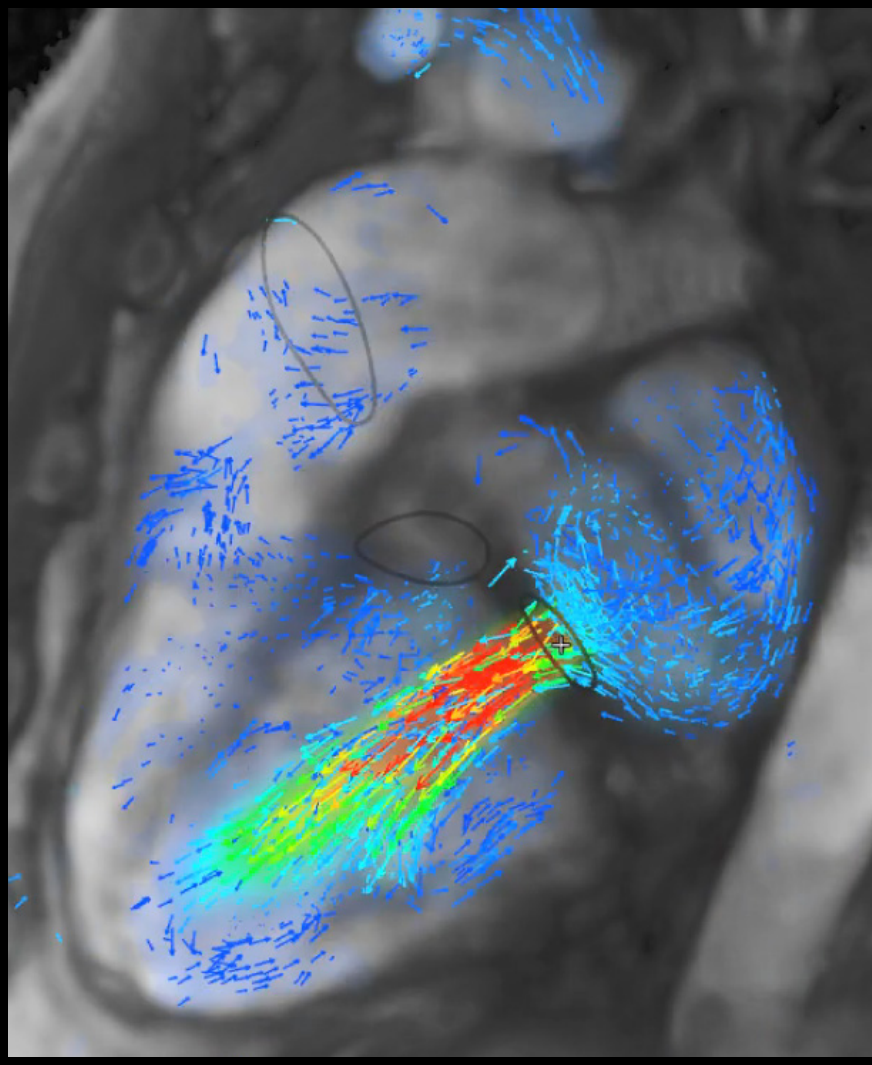

CVWorks

A collection of articles from SIGNA™ Pulse of MR

2021 Edition

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> Whatever the anatomy, AIR™ Recon DL works very well especially with cardiac exams. The SNR is increased with sequences that suffered from a lack of signal such as Single Shot MDE or Perfusion (time course), I can achieve a high spatial resolution while keeping a high temporal resolution without sacrificing SNR. It's really impressive.

Christopher Ahlers, MD
Radiomed Wiesbaden, Germany

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Matthias G. Friedrich,
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Cardiac MR in times of COVID-19

by Matthias G. Friedrich, MD, FESC, FACC, MSCMR, Professor of Medicine and Diagnostic Radiology, McGill University Health Centre, Montreal, Quebec, Canada

Coronavirus (COVID-19) is a disease caused by a novel virus, SARS-CoV-2, where SARS stands for severe acute respiratory syndrome. Although this is not the first variant of a coronavirus – both SARS and MERS were prior coronaviruses that underwent animal-to-human transition – COVID-19 does appear to be more contagious than its predecessors or the typical influenza virus.

Many people infected with COVID-19 are asymptomatic. However, certain populations are at a substantially higher risk, including the elderly (over 65 years old) and those with immunosuppression and pre-existing lung and cardiovascular disease1. Obesity also appears to be a particularly strong risk factor.

Historically, in terms of deaths, there have been larger pandemics, including the 40-50 million people who died from the Spanish flu of 1918-1919 and the ongoing AIDS/HIV epidemic that has killed up to 35 million people since 1981. We don't yet know the full impact COVID-19 will have on our society, economy and healthcare. The brutality of how the pandemic flooded certain countries led to partial collapses of regional healthcare systems. This is why it is important to think about how to address this pandemic. Countries such as Australia, Austria, South Korea and Norway that responded very quickly with lockdowns to reduce the spread of the virus did better in terms of overall death rates[2]. It appears, for the time being, that earlier restrictions had a positive impact on community spread and mortality, while a final evaluation of different strategies will not be possible for at least another year.

During the ongoing pandemic, people are also dying from other causes because they either are afraid of going to emergency rooms or because some hospitals are overwhelmed with COVID-19 patients. In New York City, a severely affected region, there are excess deaths not attributed to COVID-19, including patients who are waiting for urgent interventions they cannot receive3. Furthermore, the pandemic is already having a significant impact on the US economy, leading to an unprecedented spike in unemployment and downstream effects that will affect society for several years.

COVID-19 impact on the cardiovascular system

The SARS-CoV-2 virus enters the body's cells through the angiotensin converting enzyme 2 (ACE2) receptor that is involved in regulating blood pressure and the vascular permeability, and that is especially prevalent in the lungs and heart. After an incubation period of four to six days, typical symptoms such as sore throat, dry cough, fever, myalgia and loss of smell and/or taste occur. Not all COVID-19-positive patients will experience each of these symptoms, whereas fever, cough and a sore throat are frequent.

The first symptom of severe disease, often four to six days after the first clinical signs, is dyspnea (shortness of breath). COVID-19 can lead to extensive necrotic inflammation in the lungs, associated with a poor prognosis. Recent findings suggest that SARS-CoV-2 infection causes endotheliitis in several organs that may cause a massive inflammatory response leading to local formation of blood clots[4]. Resulting pulmonary

embolism may explain why people with COVID-19 experience a sudden deterioration of their respiratory function. Another aspect of this virus is the potential for increased permeability of the blood vessels through the ACE2 receptor, leading to an escalation in edema.

The disease progresses in three pathological stages: infection, pulmonary phase and severe disease caused by hyperinflammation[5]. In the first phase, viral infiltration and replication occurs with lymphocytopenia, a key laboratory finding. As the disease advances to the pulmonary phase, patients experience respiratory compromise and abnormal chest imaging. In the third and most severe phase, massive inflammation typically leads to extensive pulmonary damage with a subsequent lack of oxygen and finally multiorgan failure[5].

This very strong response by the immune system has also been called the cytokine storm and it may initiate more damage than the virus itself, causing some of the young COVID-19 patients to be severely affected.

A high incidence of acute myocardial injury, likely around 20 percent, is associated with poor prognosis and therefore a potential target for aggressive treatment[6]. According to early reports, up to 50 percent of COVID-19 patients with acute myocardial injury may die[6].

Elevated biomarkers such as troponin and clinical symptoms including arrhythmia, palpitations, heart failure and sudden death indicate acute myocardial injury. Acute coronary syndrome involving the coronary arteries can lead to ischemic injury or an ischemic event, such as myocardial infarction.

A consensus paper from the Society for Cardiovascular Angiography and Interventions (SCAI), American College of Cardiology (ACC) and the American College of Emergency Physicians (ACEP) recommends additional non-invasive evaluation in patients with an unclear or unequivocal diagnosis. Potential causes for myocardial injury can be ST-elevation myocardial infarction (STEMI), viral invasion itself, the inflammatory response of an overly active immune system or a mismatch systemic of oxygen supply and demand[7]. Therefore, if there is evidence of myocardial injury without a known etiology, more information is needed for informed clinical decision-making. Among various non-invasive diagnostic procedures, cardiac MR (CMR) has a unique potential.

Using CMR in COVID-19

CMR imaging enables the visualization of anatomy, function and tissue pathology. Reports on myocardial injury in patients with COVID-19 are still scarce, with one case of ischemic injury with involvement of a coronary artery[8], and another with acute myocardial injury that was apparently caused by a direct inflammatory response and not an underlying coronary artery issue. In the latter case, T2 maps (from CMR) depicted evidence of pericardial effusion in the pericardial sac. In the short axis view of the left ventricle, there was evidence of myocardial edema, as indicated by increased T2 times of the more apical myocardium as well as the bright area indicative of increased water content consistent with myocardial edema as depicted in a PS MDE sequence in a four-chamber view[9]. A recent case report confirmed this pattern[10]. Additionally, a recent study indicated a substantial incidence of persisting myocardial edema in patients having recovered from COVID-19[11]. If confirmed, these results may suggest a significant role of CMR in the care of patients with persisting symptoms after a COVID infection.

Because of its versatility, CMR is the technique of choice for a comprehensive assessment of the heart, specifically with respect to visualizing tissue pathology and thus specifically verifying or refuting the underlaying cause of cardiac disease. It can help identify ischemic versus non-ischemic injury, where ischemic injury always involves the subendocardial layer while non-ischemic rarely does[12].

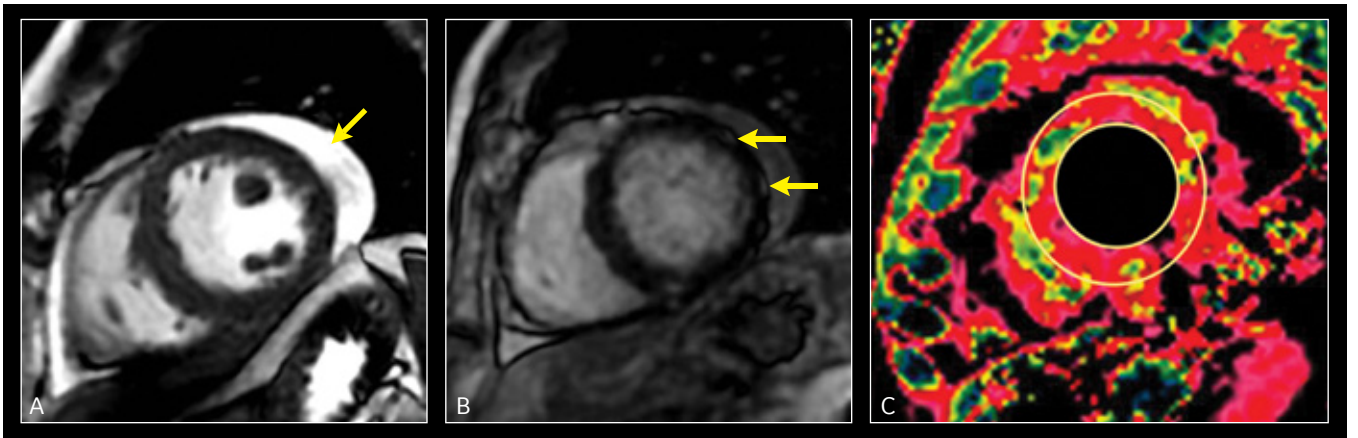

Figure 1. CMR findings in short axis views of a patient with COVID-19-related acute myocarditis. (A) Cine image with pericardial effusion (arrow); (B) late enhancement (MDE) image with mild patchy inflammatory necrosis (arrows); (C) T2 map showing increased T2 values (in red) for the entire LV myocardium, consistent with widespread myocardial edema. The LV volume was small and the resulting cardiac output reduced, despite tachycardia.

Regional distribution of the injury also indicates ischemic or non-ischemic injury; there are certain patterns that most often provide specific additional information on the origin of the injury[13], such as cardiomyopathies or certain infiltrative diseases.

Figure 1 shows a case of acute myocardial inflammation in a patient with COVID-19.

Except for very few diseases – sarcoid and myocarditis – the underlying cause of myocardial injury can generally be identified by the regional distribution.

Among them, myocarditis (inflammation of the heart muscle) can be identified quite specifically with CMR using a combination of CMR "sequences" (protocol components), including mapping, cine imaging and late enhancement (MDE).

MDE imaging requires the administration of a contrast agent and can detect irreversible myocardial injury such as necrosis, infiltration or fibrosis/scars. The Lake Louise Criteria for the assessment of patients with suspected myocardial inflammation provides CMR protocol standards and diagnostic criteria for identifying myocarditis[14]. There are main criteria for edema/acute inflammation (based on T2 as a water-sensitive marker that can be measured in CMR images) and irreversible myocardial injury in a non-ischemic regional distribution pattern. Supportive criteria include pericardial effusion and systolic left ventricular dysfunction[15].

Safety of CMR in COVID-19 patients

CMR is considered the non-invasive gold standard for verifying or refuting a diagnosis of acute myocarditis. In COVID-19 patients, it's not just the accuracy of the technique, it's also keeping the healthcare staff safe.

The virus is transmitted through the endothelium, particularly the mouth, nose and eyes. Transmission occurs through droplets and contaminated surfaces. Longer distance aerosol transmission of 1 to 2 meters is possible if enough of the virus droplets are in the air and 6 to 8 meters around infected persons who are sneezing and coughing. The World Health Organization recommends at least 3 feet and the Centers for Disease Control and Prevention suggests 6 feet for safe social distancing[16,17].

It seems apparent that many of the countries with severe sudden outbreaks of COVID-19 are the result of mass gatherings that served as a catalyst for rapid spreading: a mass religious gathering in South Korea, carnival in Germany, and beach parties in Italy and Florida. Therefore, if the healthcare staff has to work in a confined space without sufficient air filtering, the high risk is quite obvious.

While an MR exam does not generate the same risk for patient aerosols that intubation or resuscitation do, there is the risk that all patients can be carriers, even those who are asymptomatic or have a negative test.

Therefore, during a pandemic, all patients should be considered as potential virus carriers. Accordingly, all staff members associated with the scan should have proper training in donning and doffing, as well as sufficient personal protective equipment (PPE).

Given the increased risk, surgical masks are not sufficient to efficiently protect the healthcare worker. Therefore, N95/FFP2 masks, face shields or protective glasses, gloves and an impermeable gown should be used in the presence of COVID-19 positive patients.

There are a few additional important considerations. A focused CMR protocol that reduces the time a patient is in the scanner should be utilized to reduce the risk of droplets in the scanner bore. Non-contrast scans that don't require an IV should be used when possible to avoid close contact with the patient and the risk of droplets. After the scan, it is important to carefully clean all surfaces that have been potentially contaminated, similar to the extended cleaning protocols that exist in many facilities with critically ill or intubated patients. Leaving the scanner room empty for 30 minutes after an exam allows for proper ventilation.

Clinical MR workflow

COVID-19 patients with a clinical suspicion of acute myocardial injury should be frequently (every 24 to 48 hours) checked for ST elevation in ECG, shortness of breath not otherwise explained, arrhythmia or atypical chest pain. Troponin, a sensitive serologic marker, should be measured in all patients with suspected acute myocardial injury. If troponin is elevated, a cardiac MR scan can differentiate normal from acute non-ischemic injury. Furthermore, it can also differentiate between numerous non-ischemic myocardial diseases.

CMR has been shown to have a strong impact on clinical decision making, such as whether the patient goes to cardiac catheterization or receives aggressive heart failure treatment, and, therefore, also on patient outcomes[18].

If the heart appears relatively normal on CMR, then further diagnostic testing for other underlying causes, e.g., lung injury, is warranted. In late April, the Society for Cardiac Magnetic Resonance (SCMR) published recommendations for the use of CMR during the COVID-19 pandemic[19]. The authors recommended standard or rapid CMR protocols for these patients

SCMR CMR recommendations for scanning patients with known or suspected COVID-19 disease[20]

1.	LV structure and function : Short axis, 4-chamber, 2-chamber and 3-chamber FIESTA cine images
2.	T2-weighted sequences (STIR) (myocardium/pericardium)
3.	Parametric Mapping (T1-native, T2, T1-post)
4.	Acquisition based myocardial strain (Tagging, DENSE, fSENC)
5.	Vasodilator stress perfusion
6.	MDE: Short axis; Long axis
7.	2D-flow (aorta & pulmonary arteries)
8.	4D Flow
9.	Angiography (pulmonary vessels)
10.	Lung imaging

Color code: Minimum (-15 min. protocol) Minimum (-30 min. protocol) Optional

Figure 2. SCMR has published recommendations for the clinical application of CMR during the COVID pandemic. In patients with suspected cardiac complications due to COVID-19, the recommendations are to perform a core CMR protocol focused on function and tissue characteristics.

based on clinical indication. The SCMR continued to lead on this important topic by releasing guidance on CMR protocols for scanning active or convalescent COVID-19 infected patients in early September[20]. Today, there is a greater understanding that, even in patients who have recovered from the symptoms of this novel coronavirus, there may be lasting impact on the heart and lungs. This is an area of further study.

One additional important aspect regarding the use of MR in COVID-19 patients is that it can be used to examine other organs. In an unpublished case report of a patient in Iran undergoing an MR for breast disease, pulmonary findings consistent with COVID-19 were detected. Peripheral inflammation in the right lung was depicted in the T2-weighted images. The patient subsequently tested positive and developed moderate symptoms. This case indicates that in one scan, MR could double rule-out both pulmonary and cardiac involvement without the use of contrast. Although CT angiography has a higher spatial resolution, this case illustrates that with a cardiac MR scan the clinician can examine both the lungs and the heart and avoid a separate CT scan, avoid another transport through the hospital and possibly save precious therapeutic decision-making time.

To summarize, CMR can play a critically important role in the workup of COVID-19 patients with signs of acute myocardial injury. Further, it can be combined with T2-weighted lung sequences as a double rule-out of myocardial and pulmonary injury and thus render CMR the role of a fast, highly efficient exam in all patients with suspected COVID-19. The safety of technologists should be ensured by proper training and availability of adequate PPE.

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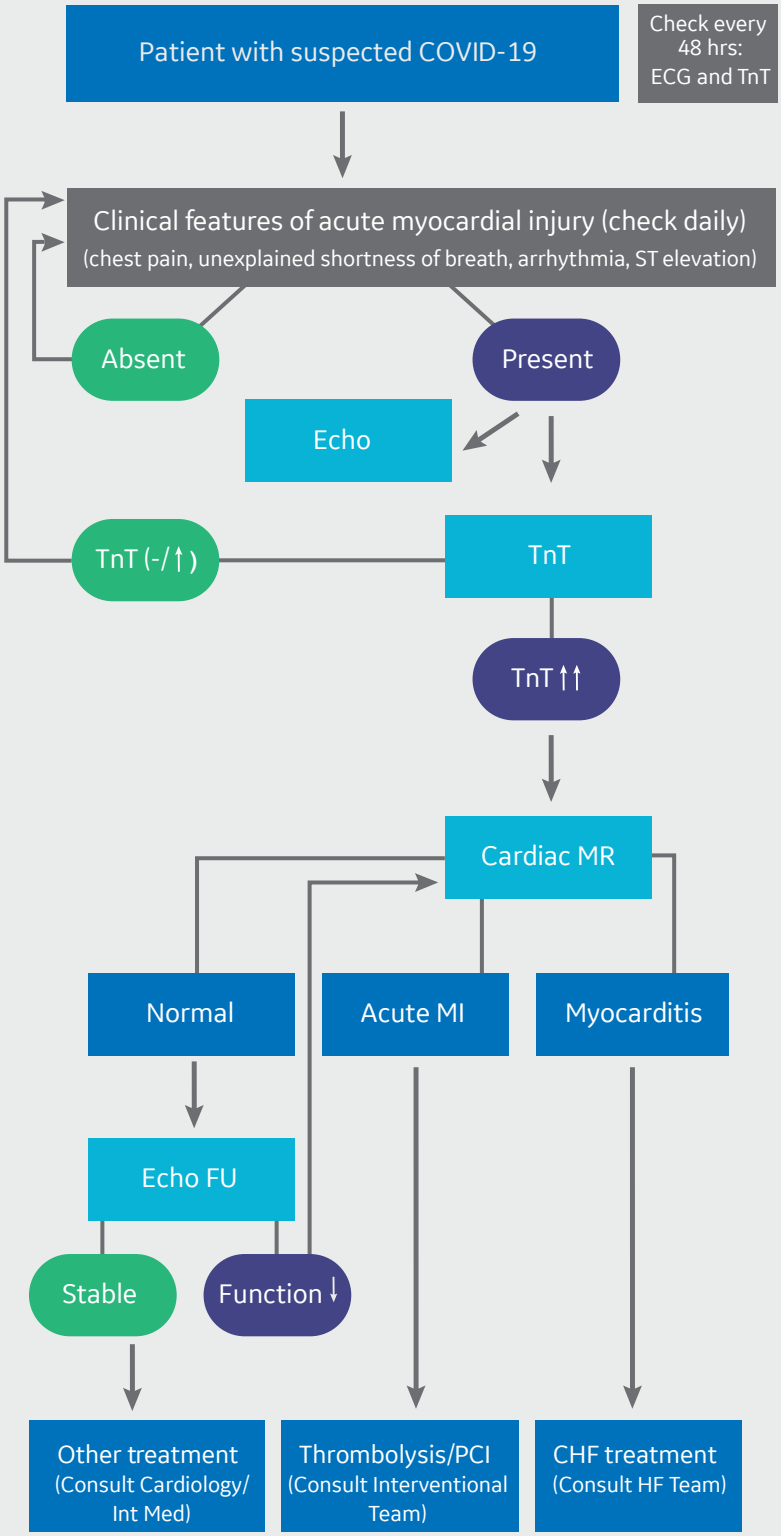

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Figure 3. Suggested role of CMR during the COVID-19 pandemic.

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Cardiac MR in patients with CIEDs

By Karl Vigen, PhD, Senior Scientist, and Christopher Francois, MD, Professor, University of Wisconsin Hospital, Madison, WI

MR imaging volume in patients with Cardiovascular Implantable Electronic Devices (CIEDs) is growing due to the adoption of MR-Conditional devices. Modified cardiac protocols can address common artifacts and distortions resulting from the device, battery or other electronic components, while also complying with MR-Conditional device labeling.

MR imaging was historically contraindicated for patients with CIEDs including pacemakers, implantable cardioverter defibrillators (ICDs), and cardiac resynchronization therapy pacemakers and defibrillators (CRT-P/Ds), due to concerns over possible lead heating, device migration and device malfunction. However, recent CIED development has led to devices with improved resistance to environmental electromagnetic interference, and many recent models have MR-Conditional labeling with approval from regulatory agencies such as the FDA.

As more patients are implanted with MR-Conditional devices, our volumes have grown (see Figure 1) to more than 100 in 2018. The adoption of MR-Conditional implants improves access and the use of MR in these patient subgroups.

Due to the location of the CIED generator, most commonly in the left upper chest, distortions in B0 and B1 due to the battery and other electronic components can lead to severe artifacts in cardiac MR (CMR), particularly with ICDs and CRT-Ds. Nearly five years ago, our institution developed a modified CMR protocol for use in patients with CIEDs.

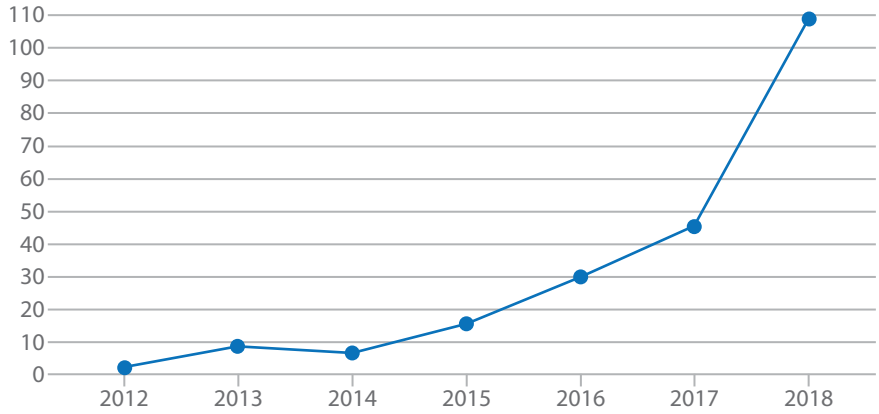

Figure 1. Number of MR exams in patients with MR-Conditional devices, all types (cardiac and non-cardiac) at the University of Wisconsin Hospital.

Prior to the imaging exam, a cardiac device nurse programs the patient's device to the pacing parameters corresponding to the device's "MRI mode" or another acceptable mode, as determined by the device clinic team. This is generally a setting such that pacing is off, or a backup mode such that the patient's underlying rhythm is maintained. Occasionally, an asynchronous pacing mode can be used, which paces the patient's heart at a regular rate, and can greatly improve MR image quality compared to an irregular heart rate.

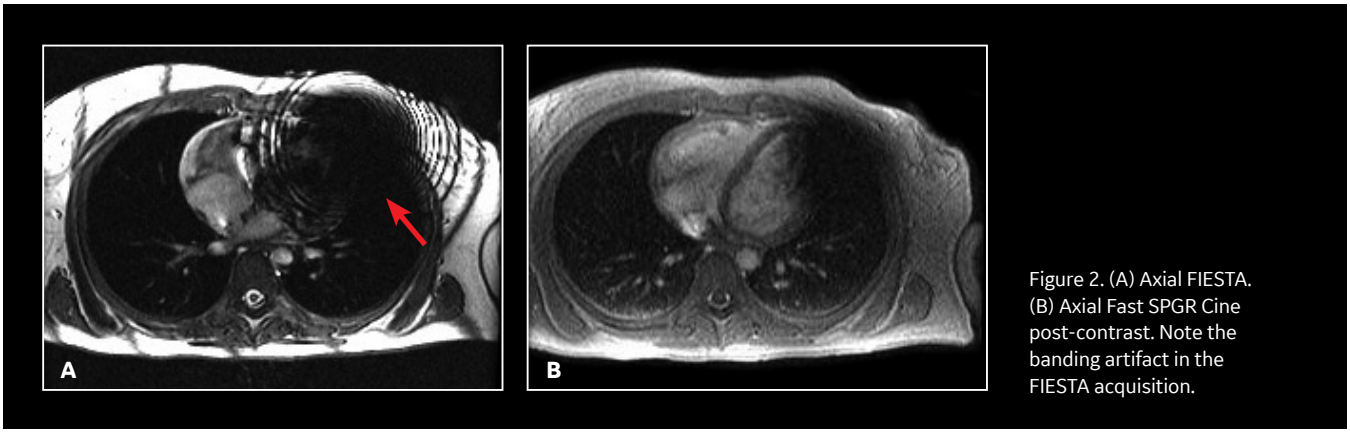

Figure 2. (A) Axial FIESTA. (B) Axial Fast SPGR Cine post-contrast. Note the banding artifact in the FIESTA acquisition.

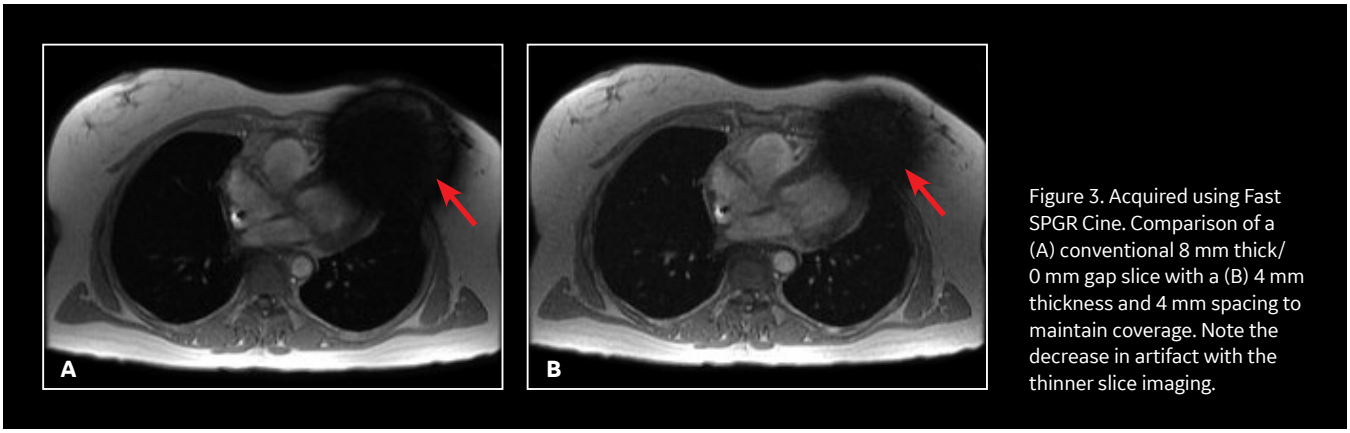

Figure 3. Acquired using Fast SPGR Cine. Comparison of a (A) conventional 8 mm thick/ 0 mm gap slice with a (B) 4 mm thickness and 4 mm spacing to maintain coverage. Note the decrease in artifact with the thinner slice imaging.

Patient positioning in the MR scanner is similar to exams in patients without devices. The patient is connected to a patient monitoring system, so that the patient's ECG and pulse oximetry information can be monitored throughout the exam. In addition, we attempt to have the patient place their arms over their head, as this can move the device away from the imaging field-of-view (FOV) and reduce the amount of main magnetic field (B_0) modulation near the imaging FOV.

FIESTA imaging sequences can contain banding artifacts due to B_0 field modulations; the artifacts can be particularly troubling due to the intense B0 modulation caused by the CIED. These artifacts are usually more severe with ICDs compared to pacemakers. By using a Fast SPGR Cine imaging sequence, the banding artifacts can be removed, albeit with a reduction of blood-to-myocardium contrast-to-noise ratio (CNR). Acquiring the short- and long-axis Fast SPGR Cine images following contrast agent administration can improve CNR, and has the additional benefit of decreasing total exam time (since there is normally 10 minutes of waiting following contrast agent administration). Figure 2 shows a typical image acquired with FIESTA (2A) and post-contrast Fast SPGR Cine (2B) in a patient with an ICD.

Using thinner slices to reduce through-slice dephasing can also help reduce artifact. In Figure 3A, a more conventional 8 mm thick/0 mm gap slice was used with Axial post-contrast Fast SPGR Cine; in Figure 3B, a slice at the same location with 4 mm thickness and 4 mm spacing to maintain coverage with fewer artifacts was utilized. Disadvantages include increased TE with reduced slice thickness and reduced SNR, although the CNR between blood and myocardium can be improved if acquired post-contrast.

For late gadolinium enhanced (LGE)/ myocardial delayed enhancement (MDE) imaging, an inversion pulse with an appropriate TI is used to suppress signal from normal myocardium, highlighting signal from infarcted myocardium. With conventional MDE imaging, B_0 inhomogeneity could cause incomplete inversion and artifactual high signal in normal myocardium could be mistaken for infarction. A new wide-bandwidth adiabatic inversion pulse for MDE (standard in GE's DV26.0 software) allows suppression of myocardial signal without artifactual high signal (see clinical cases). When combined with the Phase-Sensitive Inversion Recovery (PSIR) option, high image quality can be achieved (Figure 4). We do not use the single-shot

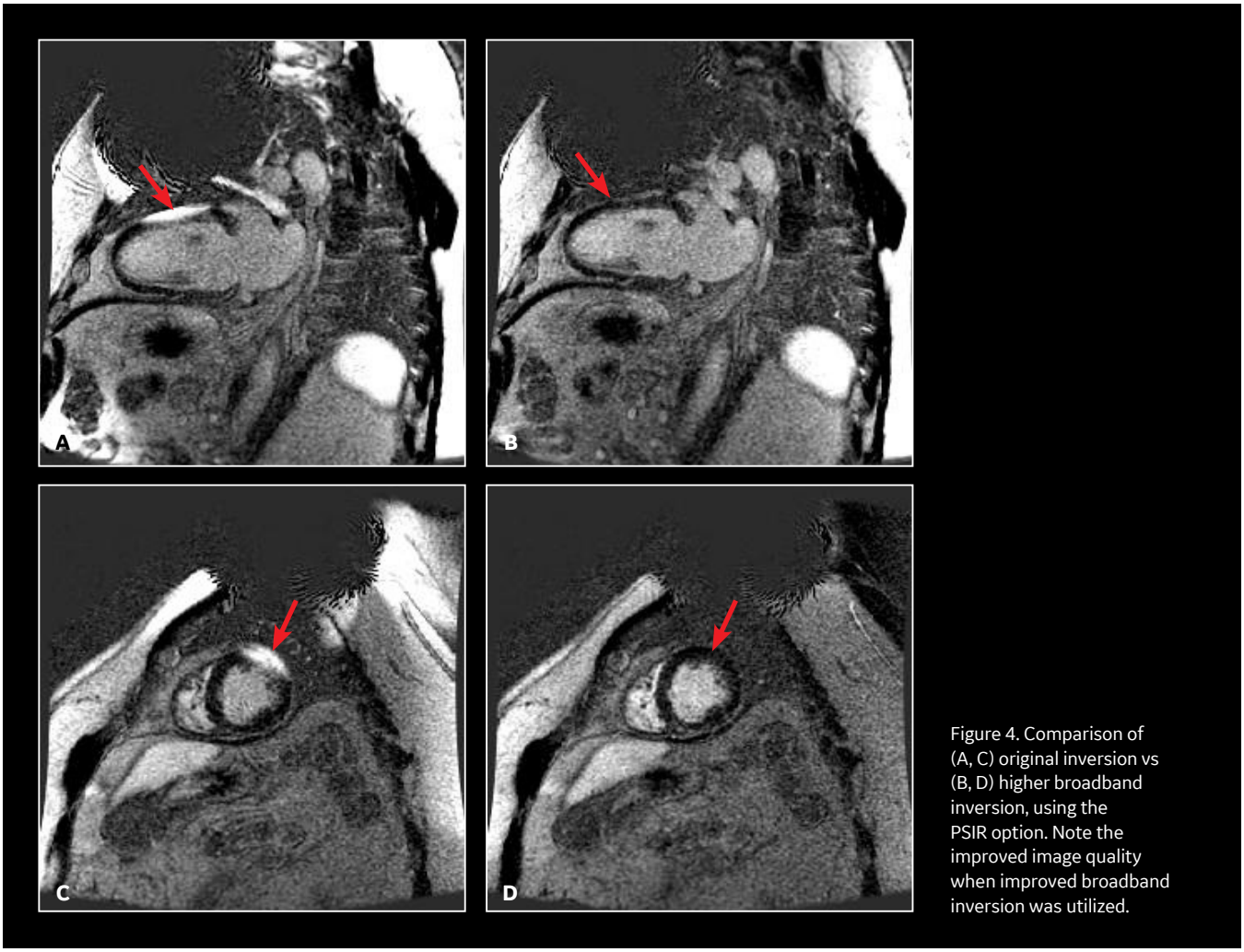

Figure 4. Comparison of (A, C) original inversion vs (B, D) higher broadband inversion, using the PSIR option. Note the improved image quality when improved broadband inversion was utilized.

MDE sequence (SS MDE) at 1.5T for these patients, since this uses a FIESTA readout combined with parallel imaging; the combination is prone to artifactual high late enhancing signal.

We image all MR-Conditional CIED patients at 1.5T, with SAR and dB/dT set to Normal Operating Mode, which has a whole body SAR limit of 2.0 W/kg. Recent versions of GE software include a Low SAR mode, allowing the user to specify even lower limits for SAR or B_{1+RMS}. Most MR-Conditional CIEDs specify 2.0 W/kg for SAR at 1.5T; however, those that are MR-Conditional at 3.0T can have lower limits. For example, the Medtronic Advisa DR/SR MRI pacemakers specify maximum B_{1+RMS}=2.8μT for thoracic imaging, which can be easily set in Low SAR mode. The availability of 3.0T imaging combined with low SAR mode is expected to be important if the scan is clinically indicated for 3.0T (e.g., PET/MR) or for institutions without access to a 1.5T system.

Currently, all patients with MR-Conditional CEIDs are scanned on a wide bore 1.5T MR system in our facility, assuming specifications for field strength and maximum spatial gradients of the static field in the MR-Conditional device labeling can be met. We find the wider bore is particularly helpful when imaging patients who cannot easily hold their arms above their head. Additionally, employing rapid sequences may reduce scan times and enhance patient comfort and compliance; however, our institution has not yet evaluated rapid sequences for CMR imaging in patients with MR-Conditional devices.

Recently, GE introduced lightweight AIR™ Coils. While we have not had an opportunity to use the AIR™ Coils for imaging patients with CIEDs, our current experience for cardiac imaging on our 3.0T SIGNA™ Premier systems demonstrate excellent image quality. We anticipate improved patient comfort for these exams, which may facilitate improved compliance for arms-above-head positioning.

Case 1

Patient with a history of dilated cardiomyopathy and worsening ejection fraction; pacing dependent. With MR, the left atrium and left ventricle were shown to be mildly dilated. Global hypokinesis was seen with regional variation specifically with focal hypokinesis/dyskinesis in the mid/apical septal and apical anterior segments. There is curvilinear late gadolinium enhancement consistent with scarring in the basal-anterior septal mid myocardium.

Optima™ MR450w

PARAMETERS	*Sagittal short axis Fast SPGR Cine*	*Axial long axis Fast SPGR Cine*	*Sagittal short axis PS MDE*	*Coronal and Axial long axis PS MDE*
TR (ms):	6.3	6.3	8.2	7.9
TE (ms):	2.6	2.6	3.9	3.8
FOV (cm):	38 x 38	38 x 29.3	38 x 26.6	38 x 30.4
Slice thickness (mm):	6	6	6	5
Frequency:	256	256	224	200
Phase:	160	160	192	192
NEX:	1	1	1	1
Scan time (min):	1:30 (12 slices)	0:25 (sec.) (3 slices)	1:48 (12 slices)	0:42 (sec.) (4 slices)

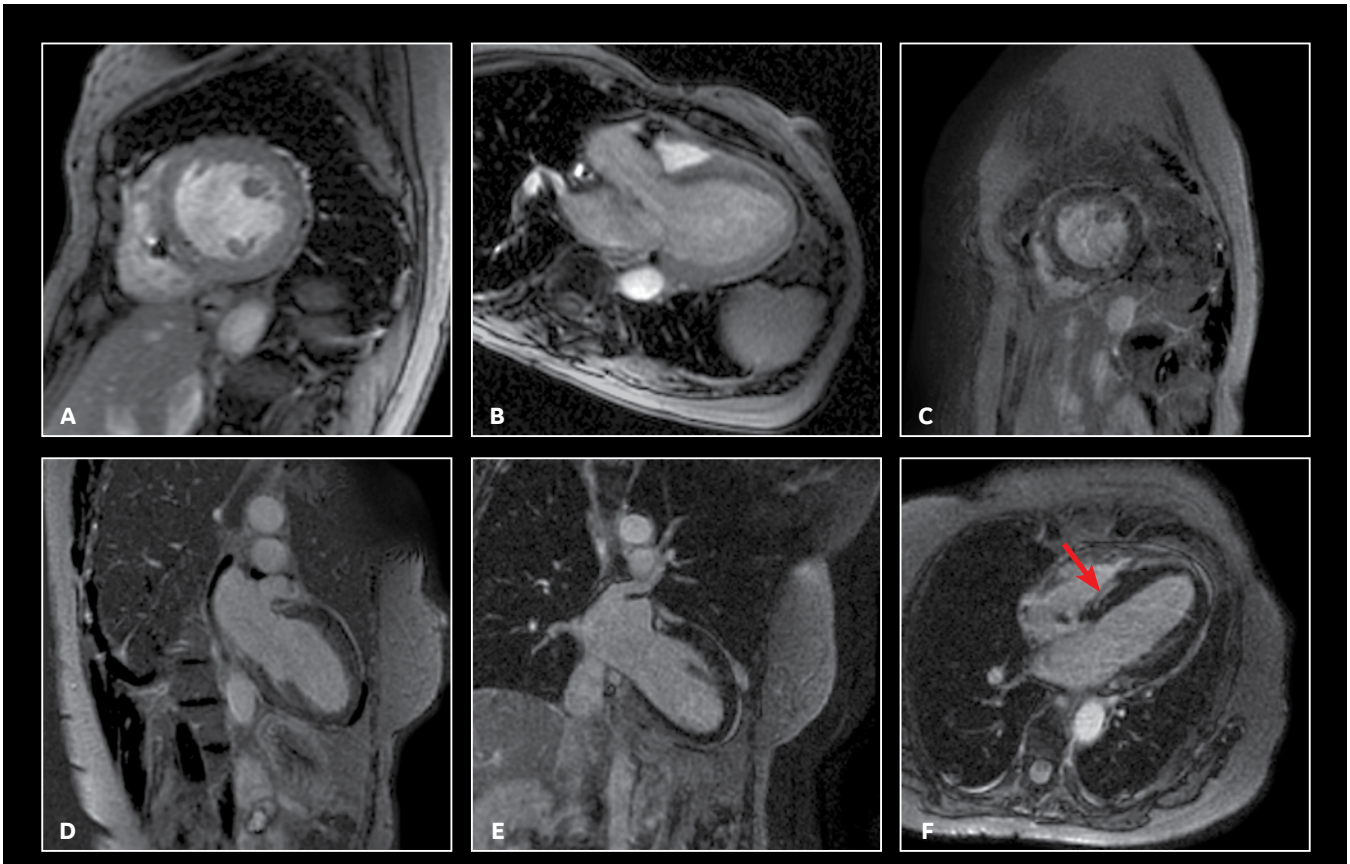

Figure 5. (A) Short axis Fast SPGR Cine; (B) long axis Fast SPGR Cine; (C) short axis MDE (arrow); (D-F) long axis MDE.

Case 2

Patient with a history of ventricular tachycardia with possible left ventricular thrombus. MR shows enlarged left ventricle, with global hypokinesis with dyskinesis in the apical anterior wall and true apex. Thrombus is seen in the apex, with a thin rim of increased enhancement at the edges of the thrombus. There is subendocardial to transmural enhancement in the apex. S

Optima™ MR450w

PARAMETERS	*Coronal short axis Fast SPGR Cine*	*Axial long axis Fast SPGR Cine*	*Long axis PS MDE*
TR (ms):	5.3	5.3	5.9
TE (ms):	2.4	2.4	2.8
FOV (cm):	40	40	40
Slice thickness (mm):	6	6	6
Frequency:	192	192	192
Phase:	160	160	192
NEX:	1	1	1
Scan time (min):	1:21 (12 slices)	0:20 (sec.) (3 slices)	0:49 (sec.) (3 slices)

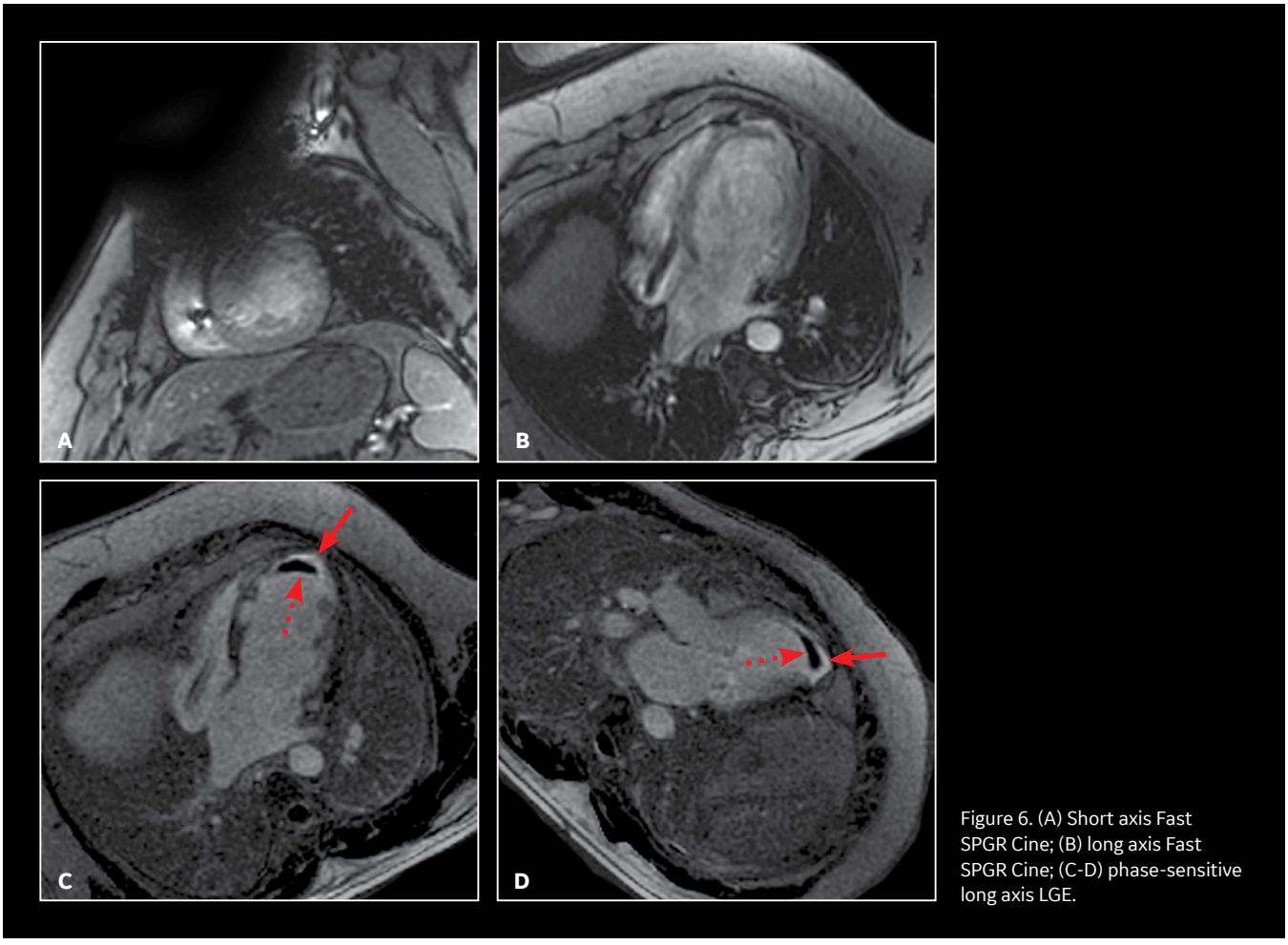

Figure 6. (A) Short axis Fast SPGR Cine; (B) long axis Fast SPGR Cine; (C-D) phase-sensitive long axis LGE.

Edwin Oei, MD, PhD
Erasmus Medical Center
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AIR: a brilliant improvement in high-quality imaging and patient comfort

As one of the first sites in the world to install SIGNA™ Premier and AIR™, Erasmus Medical Center is a leader in adopting cutting-edge technologies. These new solutions are providing a better patient experience while delivering high-quality imaging and advanced applications, further enhancing the excellent care provided by clinicians at Erasmus.

Erasmus Medical Center in Rotterdam, Netherlands, is a leading university medical center in Europe and has long been recognized for its adoption of cutting-edge technologies and advanced medical solutions. For the last few years, Erasmus has collaborated with GE Healthcare to evaluate the introduction of new technologies into the clinical environment. One of these is AIR™.

AIR™ Coils are designed to fit all patients, allow flexibility in any direction and closely wrap around the patient's anatomy for greater visibility of hard-to-scan areas with excellent image quality. By conforming to the patient habitus and bringing the coil elements closer to the patient, AIR™ improves signal quality and signal-to-noise ratio (SNR) and reduces imaging artifacts when compared to previous generations of conventional coil technology.

Recently, several clinicians from Erasmus shared their initial impression of AIR™ on the SIGNA™ Premier 3.0T MR system, including the AIR™ Anterior Array (AA) Coil, the AIR™ 48-channel Head Coil and AIR Touch™.

Cardiac imaging

Alexander Hirsch, MD, cardiologist, specializes in non-invasive cardiac imaging. In cardiac patients, Dr. Hirsch scans cardiomyopathy and ischemic heart disease patients on SIGNA™ Premier. Typically, the 2D FIESTA, first-pass perfusion and MDE images are the most common sequences for these patients. Image quality is important, particularly in the late enhancement (MDE) sequence where Dr. Hirsch evaluates myocardial viability. With the 2D FIESTA sequence, he is looking at cardiac function. However, 2D FIESTA sequences have historically been problematic at 3.0T.

"The new SIGNA™ Premier system is especially good for late enhancement images and also for perfusion," Dr. Hirsch says. "I was able to see the anatomy and the function, as well as differentiate the contrast between the blood and the myocardium. Previously in a 3.0T system, that was a problem, however, with the SIGNA™ Premier this has improved a lot."

A key factor in the improved image quality is AIR™. Dr. Hirsch says he gets a more homogeneous signal and better contrast between the blood and the myocardium.

Juan Hernandez Tamames, PhD
Erasmus Medical Center
Rotterdam, Netherlands

Watch Dr. Hirsch's 2019 SCMR presentation, "Getting consistent and quantifiable results in cardiac imaging:" https://youtu.be/dQ3-sU-kPv0

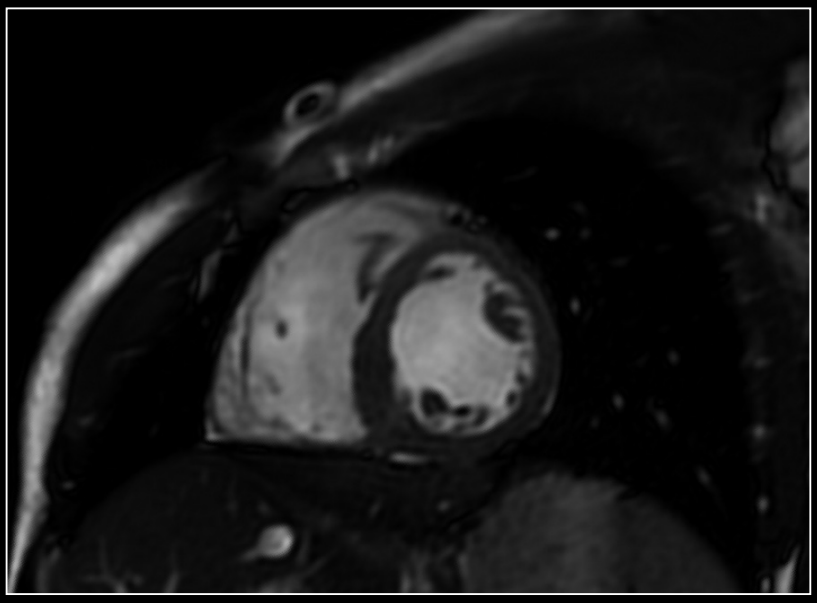

Figure 1. Short axis 2D FIESTA. The combination of SIGNA™ Premier and AIR™ delivers high SNR and high image quality for excellent cardiac MR imaging results at 3.0T.

"Because of the specialized nature of our facility, with referrals from all over the Netherlands, it is important to have the latest technology," he says. "With the new GE SIGNA™ Premier and AIR™, we can provide high- quality care for our patients."

"The new AIR™ AA Coil has a major advantage in that it helps provide high image quality," Dr. Hirsch adds. Plus, with SIGNA™ Premier he has been able to achieve high SNR, which is very important for the sequences he is using. Dr. Hirsch also expects to see improvements in 4D Flow (ViosWorks), as well as the new 3D MDE sequence.

"When we started working with SIGNA™ Premier, I was pleasantly surprised to see the image quality, especially for the 2D FIESTA sequence," he says.

Brendan Bakker, MR radiographer, has developed cardiac MR (CMR) protocols at Erasmus with Dr. Hirsch. While 1.5T was typically preferred for CMR, he worked with Dr. Hirsch to evaluate CMR exams on the SIGNA™ Premier 3.0T MR system with AIR™.

"The AIR™ AA Coil is brilliant and it's an improvement for the patient. It is very easy to handle, very lightweight and the quality is very good for cardiac imaging, especially on the SIGNA™ Premier system," Bakker says.

"The AIR™ AA Coil is very flexible, you can put it around the chest or stomach but also use it around the knee or shoulders," Bakker says. "With other coils that are more rigid, this is not possible."

In pediatric imaging, the AIR™ Coils fit almost like a blanket on the child, he adds.

MSK imaging

Edwin Oei, MD, PhD, is an Associate Professor of Musculoskeletal Imaging and Section Chief of Musculoskeletal Radiology at Erasmus Medical Center. He dedicates half his time to research and working with MR physicists and PhD students to improve technologies and apply MR imaging in population health studies.

"SIGNA™ Premier offers advantages in musculoskeletal imaging because of its

Brendan Bakker
Erasmus Medical Center
Rotterdam, Netherlands

Jean Paul Laarhoven
Erasmus Medical Center
Rotterdam, Netherlands

higher gradient performance, especially when it is used with the AIR™ Coil," Professor Oei says.

According to Professor Oei, musculoskeletal (MSK) MR imaging tends to suffer from artifacts and movement more than in other body parts. Often, there are difficulties with positioning patients due to their injury or ailment, as well as using the right coil. While coil selection is not as problematic in the knee or ankle, it can be more difficult when imaging the shoulder, wrists or ribs.

"With AIR™, we are more flexible in choosing the coil, which allows for imaging specific body parts with greater accuracy. For patients with chronic diseases such as arthritis, it may not be easy for them to lie still in the scanner for a long time with a rigid coil. The AIR™ Coil is lighter and more comfortable for the patient so, indirectly, I think it will also reduce movement artifacts."

Professor Edwin Oei

AIR™ also assists with patient positioning. When using traditional rigid coils, the body part being imaged had to be positioned precisely in the coil. With AIR™, this is less of an issue.

"We mainly now use the blanket-type AA Coil and have achieved great imaging results in the chest wall and in joints," adds Professor Oei. "I think AIR™ is beneficial for diverse patient groups, including pediatric and elderly patients."

Professor Oei believes there is a movement in MR imaging toward whole-body imaging, particularly for oncology. He anticipates that AIR™ will provide excellent results over existing coil technology due to its wide coverage.

"Since the introduction of SIGNA™ Premier and AIR™ at Erasmus, I've seen image quality improve over previous scans and I believe that AIR™ can greatly improve patient throughput," Professor Oei says.

The AIR™ family of products also includes a 48-channel Head Coil. Jean Paul Laarhoven, MR radiographer, has scanned patients with both the AIR™ 48-channel Head Coil and the AIR™ AA Coil on SIGNA™ Premier. With the ability to adjust the coil for larger-sized heads and necks, he can accommodate more patients. He has found that patients with anxiety or claustrophobia can better tolerate the AIR™ 48-channel Head Coil because the front part of the coil is slightly smaller and doesn't cover the patient's entire face.

"You can immediately see the high-quality images that the AIR™ Coil captures," Laarhoven explains. "Of course, we also have the Posterior Array (PA) in the table so we only have to position the AIR™ AA Coil on top of the patient."

Improving the patient experience

Sita Ramman has been an MR radiographer for nearly 28 years at Erasmus. Often, she has had to comfort and reassure patients who are nervous about their MR exams. She will explain that they have to remain very still and may have to hold their breath while the system acquires the images.

Since the introduction of AIR™, she has seen a noticeable difference.

"The patients like the AIR™ Coils because they are very lightweight and flexible, and mold to the patient's anatomy," Ramman says. "For us, it is very easy to position. You just put it on the patient and that's it. That's all you have to do."

She has also used AIR Touch™, an intelligent coil localization and selection tool that enables automatic coil element selection and uniquely optimizes uniformity and SNR. AIR Touch™ informs the system when the coil is connected, allows the technologist to landmark the patient with a single touch and even optimizes the element configuration. Coil coverage, uniformity and parallel imaging acceleration are generated dynamically to optimize image quality. A simplified user interface allows the technologist to focus on the patient and also maximizes examination efficiency.

"We just put the AIR™ Coil on the patient, localize using the AIR Touch™ button on the table and move the patient inside the SIGNA™ Premier," Ramman explains. "With AIR™ Coils and AIR Touch™, we don't need to do any calibration as it is done automatically. This makes a difference

Sita Ramman
Erasmus Medical Center
Rotterdam, Netherlands

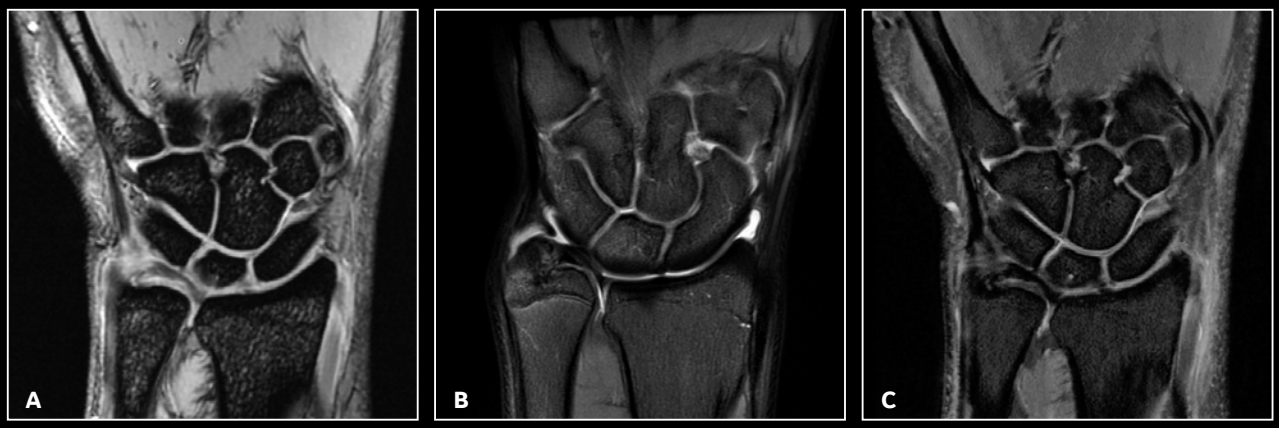

Figure 2. AIR™ Coils are flexible and assist with patient positioning in areas where coil selection may be more difficult, such as the wrist. (A) Coronal 3D MERGE; (B) Coronal PD FatSat; and (C) Coronal T2 Flex.

in our daily routine because it takes less time to position a patient."

A remarkable advance

Juan Hernandez Tamames, PhD, Associate Professor (MR) and Head of the MR Physics group in the radiology department at Erasmus, facilitates the introduction of new technology in MR imaging for both clinical and research purposes.

"SIGNA™ Premier incorporates several new approaches and breakthroughs in technology," Professor Tamames says.

"For example, the AIR™ Coils are one of the most remarkable innovations I've seen because they increase SNR."

He also discovered that the HyperBand capability on SIGNA™ Premier enables the possibility to simultaneously scan several slices, accelerating acquisition with the potential to shorten scan times when using DWI. With the parallel transmission, he can tailor the RF for specific tissues in a more appropriate way.

"Compressed sensing is another remarkable advance on SIGNA™ Premier," Professor Tamames adds. "When used with the AIR Coil™, which improves signal due to the closer proximity to the patient anatomy and tissue, we can increase the acceleration with compressed sensing and parallel imaging to reduce scan times."

For example, since the lungs are filled with air, it is often difficult to obtain good SNR. Because the AIR™ AA Coil lays on the patient's chest, it is as close to the body as possible. This enables a high SNR.

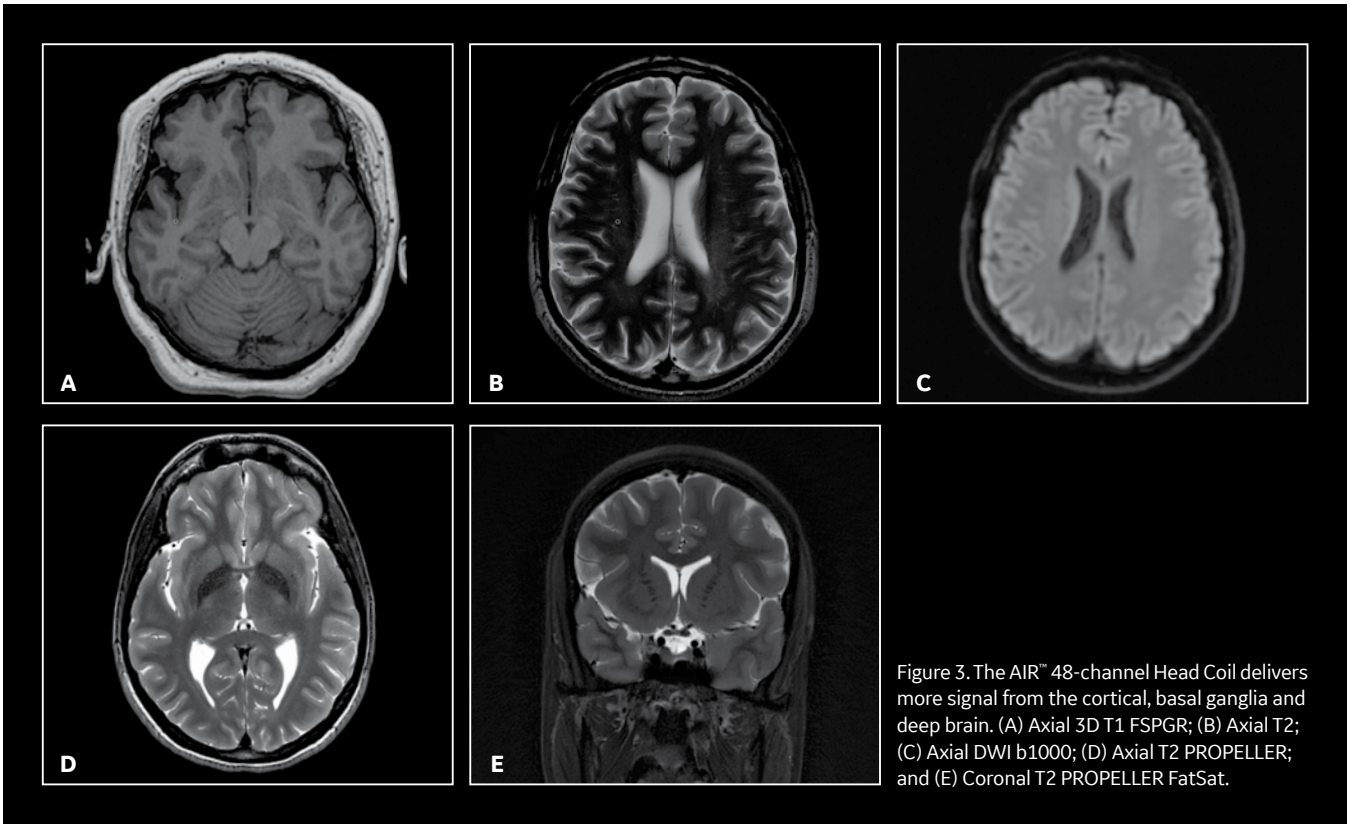

Figure 3. The AIR™ 48-channel Head Coil delivers more signal from the cortical, basal ganglia and deep brain. (A) Axial 3D T1 FSPGR; (B) Axial T2; (C) Axial DWI b1000; (D) Axial T2 PROPELLER; and (E) Coronal T2 PROPELLER FatSat.

Another advantage is in pediatric imaging. Professor Tamames says a baby can be wrapped in the coil, which makes them more comfortable and enables the coil to get closer to the anatomy.

"In general, the AIR™ Coil is more convenient and it can fit almost any sized anatomy," adds Professor Tamames.

Professor Tamames is interested in testing the AIR™ AA Coil with a conventional head coil and also with the AIR™ 48-channel Head Coil.

"With 48-channels we can accelerate more because we have a really good, high-quality signal," Professor Tamames explains. "By accelerating, we reduce the echo time, which means less distortion in an EPI sequence. And that is important for exploring the basal ganglia and frontal or temporal areas. Not only is the signal better, but the anatomy and morphology of the tissue is more realistic."

Watch the team at Erasmus discuss their experience with AIR™.
https://youtu.be/MeGebBSjUNQ

Matthew T. Bramlet, MD
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An efficient and reproducible toolset for cardiac MR image analysis

Recent advances in cardiac MR imaging and post-processing capabilities, such as higher spatial-temporal resolution and accelerated cardiac exam workflows, have reinvigorated its use in clinical practice.

To address this growing need, GE Healthcare announced the integration of cvi42 cardiovascular post-processing software, licensed from Circle Cardiovascular Imaging (Calgary, Alberta, Canada), onto its GE Advantage Workstation (AW) and AW Server. cvi42 is state-of-the-art software that delivers a comprehensive toolset for cardiovascular MR image analysis, including features such as automated contour definition, quick-editing tools and synchronized viewing schemes that simplify tasks commonly done manually. It contains a broad suite of advanced, easy-to-use modules for viewing and analyzing cardiac MR images, including heart function, flow, tissue characterization and T1 mapping and tissue parametric mapping (T2/T2*).

Matthew T. Bramlet, MD, the Director of Congenital Cardiac MRI at Children's Hospital of Illinois and an Assistant Professor of Pediatrics at the University of Illinois College of Medicine at Peoria, has been using cvi42 as his cardiac MR post-processing software tool for several years. As a pediatric cardiologist, he specializes in children with congenital heart disease, a disease present at birth where structural heart defects involving the heart muscle, valves and/or associated arteries and veins disrupt the normal flow of blood through the heart. For example, blood can flow in the wrong direction or to the wrong place, with varying impact to the patient's health depending on the severity of blood flow disruption. Accurately measuring heart morphology and blood flow is critical for proper diagnosis and treatment planning of congenital heart disease.

Fortunately, since the human cardiovascular system is a closed system of heart and blood vessels, certain cardiovascular relationships must hold true, which offers the possibility of internal validation when performing volume and flow measurements—in other words, the "numbers must match."

"cvi42 is valuable because it is an efficient and reproducible tool that allows me to standardize how to validate the numbers I provide in my reports," Dr. Bramlet says.

"When calculating left and right ventricle numbers, I want to have greater confidence in the volumetric analysis and diastolic volumes. By using a reproducible tool, I'm confident that my numbers match."

Dr. Matthew Bramlet

In particular, the thresholding segmentation contouring tool in cvi42 is easy to use on congenital exams with a quick click-n-drag mouse action that facilitates his ability to achieve the same level of thresholding in each imaging slice, and therefore generates reproducible values. With cvi42, Dr. Bramlet can apply the threshold and have a high level of confidence that the values are accurate on each slice.

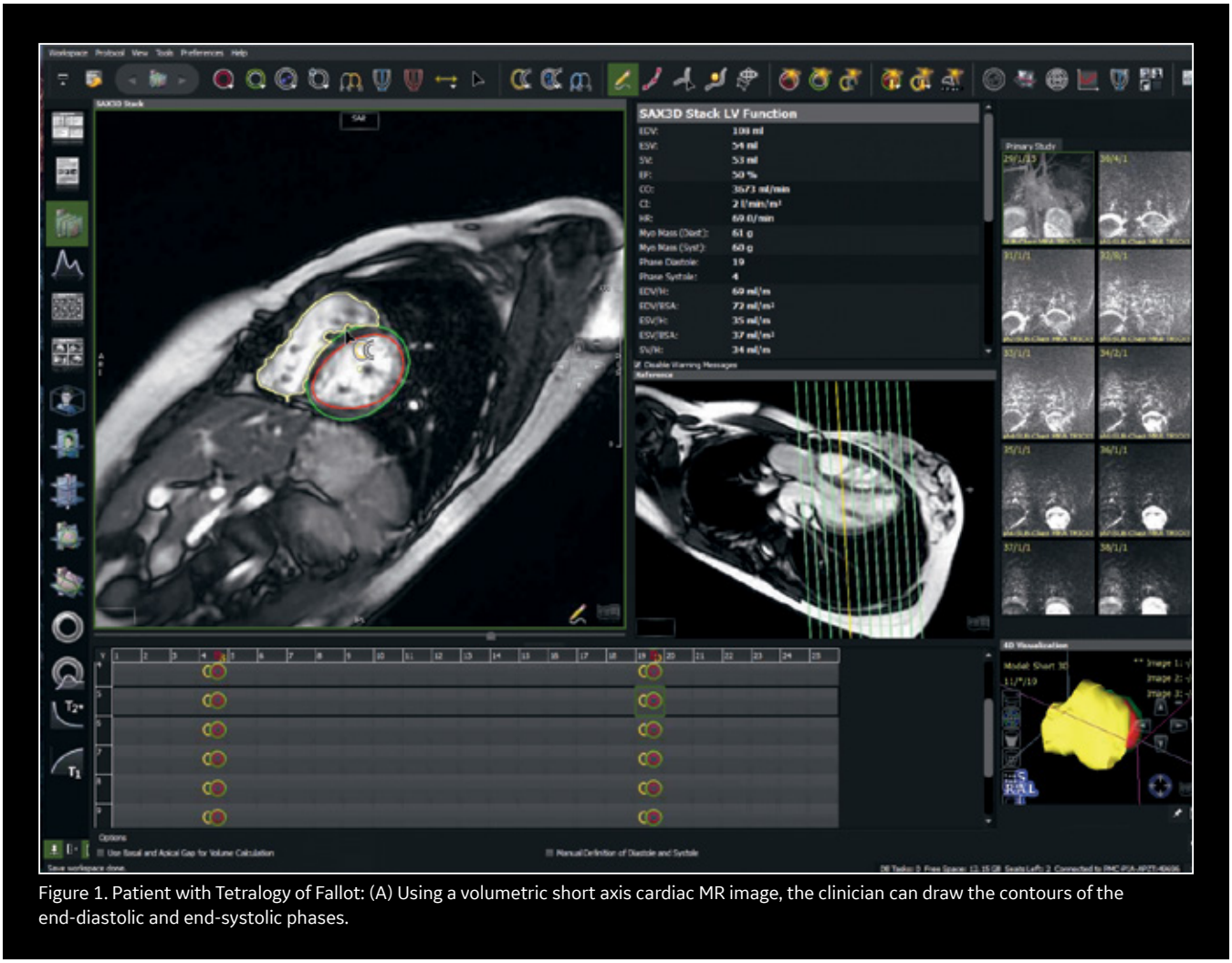

Figure 1. Patient with Tetralogy of Fallot: (A) Using a volumetric short axis cardiac MR image, the clinician can draw the contours of the end-diastolic and end-systolic phases.

When tracking the endomyocardial border, it is possible to lose the border when a ventricular trabeculation and compaction comes together. Yet, with the thresholding tool, Dr. Bramlet says he can "dive down into where the endocardium is located in a unified fashion, based on minor variations and signal intensity, and feel more confident visually when looking at ejection fraction and the right ventricle that it matches the left ventricle."

In cases of Tetralogy of Fallot, a common congenital anomaly, Dr. Bramlet uses the software to quantify right heart flow and volume. The regurgitant flow fraction measured at the pulmonary valve should match the left and right ventricular volumes. When these numbers do match, he is then confident providing the value to the surgical team for their decision-making process.

As an example, in the case of a 5-year-old patient with pulmonary regurgitation and volume overload on the right ventricle, he uses cvi42 to calculate the end-diastolic right ventricular volume just before systole. This value is often used by institutions to determine when a patient should undergo pulmonary valve replacement surgery.

"I want to derive that volume not just from a single analysis but one that is validated elsewhere in the patient imaging data," Dr. Bramlet says. "In a typical patient study, in addition to the right and left ventricular analysis, I will include aortic and pulmonary phase contrast sequences, which allow me to correlate these values. The regurgitant fraction from the pulmonary valve will frequently relate to the left ventricle and right ventricle. When these values match up, then I am more confident it is a true representation."

Dr. Bramlet finds cvi42 is not only easier and more reproducible, but it is also faster with more reliable values.

"cvi42 values are consistent with the clinical picture and easy and efficient to obtain," Dr. Bramlet adds.

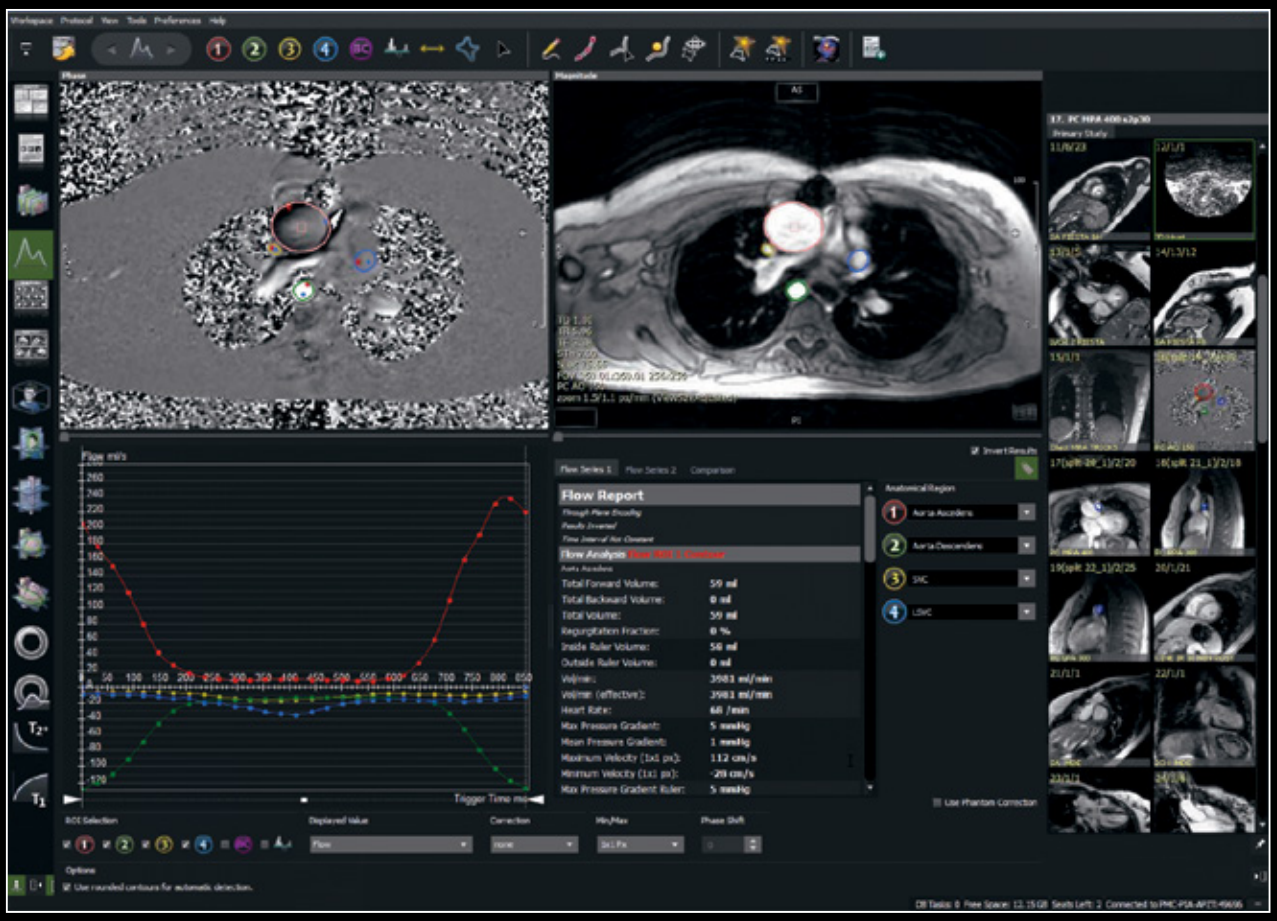

Figure 2. Patient with Tetralogy of Fallot: The flow values are important in patients with coarctation of the aorta. Selecting the ascending and descending aorta generates additional data that can be used as an internal control to validate the flow data.

In clinical practice, Dr. Bramlet will first launch the 4D viewer for an overview of the case and the volumetric display. He uses the subtracted series from TRICKS and selects a time-resolved image to render (Figure 1). Next, he finds a third subtraction series, and loads the right side of the heart structures for an ideal representation of the organ. He then processes a 3D volumetric map for visualization purposes only (no measurements) and creates a rotating cine image.

"The tools (in cvi42) allow me to move faster through the slices and image series, and facilitate movement and actions during the data manipulation so that it is more reliable. I measure the descending aorta every time for extra confidence and by doing that I feel I've gained more knowledge on the patient's condition."

Dr. Matthew Bramlet

The clinical benefits of AIR Recon DL for MR image reconstruction

By Robert D. Peters, PhD, Global Product Marketing Director, MR Applications & Visualization, Heide Harris, RT(R)(MR), Global Product Marketing Director, MR Applications & Visualization, and Steve Lawson, RT(R)(MR), Global MR Clinical Marketing Manager, GE Healthcare

The advantages of MR as a medical imaging modality are well documented, including the lack of ionizing radiation, volumetric capabilities, superior soft tissue contrast and the potential for quantitative imaging. Unfortunately, long imaging times and a lack of high spatial resolution remain as common clinical complaints and represent a major focus of present-day technical development activities.

To this end, the MR industry has addressed these needs with innovations such as parallel imaging, compressed sensing and simultaneous multi-slice for scan time acceleration.

Artificial intelligence, particularly deep-learning (DL) techniques such as AIR™ Recon DL[‡], have recently been introduced to improve image quality (SNR and sharpness) as well as enable scan time reductions.

In MR imaging, raw data is collected in the form of so-called k-space, which represents the Fourier transform of the object being imaged. Due to the finite amount of k-space that is collected in MR imaging, certain artifacts result, such as Gibbs ringing, which is also known as a truncation artifact, and occur irrespective of the pulse sequence. Gibbs ringing manifests as duplication or ringing of sharp edge structures, like cerebrospinal fluid (CSF). To reduce Gibbs ringing artifacts, raw data is routinely filtered or apodized, effectively suppressing the peripheral regions and consequently attenuating high-resolution structures.

However, suppression of Gibbs ringing through raw data filtering comes at a cost in image sharpness or spatial resolution. This delicate balance of Gibbs ringing suppression and spatial resolution is a well-known tradeoff in MR imaging.

One image quality metric that is often used to describe image quality is SNR. In MR, there are multiple sources of noise, such as thermal and electrical noise, which impact the raw data that is collected. Noise in raw data translates into noise in the final image. The typical approach to improving SNR is to perform multiple averaging, which comes at the expense of prolonged scan time, or to increase the voxel volume at the expense of lower spatial resolution. Other hardware-related solutions to improve SNR include using a higher field strength, quality surface coils and low-noise receiver components, which add to overall system cost.

MR users have become familiar with managing the tradeoff and compromise with respect to spatial resolution, SNR and scan time with conventional MR image reconstruction. In some facilities, this tradeoff has led to multiple imaging protocols. Compounding this is the increased pressure to meet ever-demanding schedules and the need to manage variables such as patient shape, size and level of cooperation. Re-scans and patient callbacks are no longer options for managing unexpected results.

To read the complete whitepaper, visit: tinyurl.com/AIR-Recon-DL-whitepaper

Enter AIR™ Recon DL

What if there was an alternative to conventional MR image reconstruction where the user did not have to choose between spatial resolution, SNR or scan time? Well, now there is. In 2020, GE Healthcare introduced AIR™ Recon DL, an algorithm that is embedded in the MR image reconstruction pipeline[1], where a neural network model is applied to remove noise and Gibbs ringing artifacts prior to final image formation. The network employs a cascade of over 100,000 unique pattern recognitions for noise and low resolution to reconstruct only the ideal object image.

[‡]Not yet CE marked for 1.5T. Not available for sale in all regions.

AIR™ Recon DL performs two separate functions within the MR image reconstruction pipeline: ringing suppression and SNR improvement. These provide for clinical benefits such as scan time reduction, sharper images, greater tolerance of protocol variations and images that are easier and faster to read.

With AIR™ Recon DL's Intelligent Ringing Suppression, part of the reconstruction-embedded deep neural network, the tradeoff of ringing suppression for spatial resolution is avoided by making images sharper and having higher spatial resolution. As such, the clinically acceptable voxel volumes for AIR™ Recon DL are larger than for conventional reconstructed images.

Based on a phantom study for equivalent spatial resolution, it is estimated that the AIR™ Recon DL in-plane voxel dimension can be approximately 1.4 times larger than that of the conventional image. This 1.4 factor is consistent with an independent study that found a factor of 1.6, based on edge gradient analysis[1]. Results from this phantom study suggest that a lower in-plane matrix setting can be used with AIR™ Recon DL to obtain equivalent spatial resolution and image sharpness as a conventional image, independent of the SNR improvement.

Addressing the tradeoff

AIR™ Recon DL provides a solution to the tradeoff with SNR, spatial resolution and scan time. To begin, SNR is usually thought of as an output metric of the image, which depends on various input protocol settings of the MR scan such as voxel volume (e.g., spatial resolution) and number of averages (e.g., scan time). There generally is no direct SNR parameter; SNR simply results from the selected MR parameters.

SNR is directly dependent on voxel volume, which is the product of the in-plane pixel dimensions with slice thickness. Voxel volume is typically used to characterize the prescribed spatial resolution. It is generally intuitive to most MR users that the larger the signal-bearing voxel volume, the greater the SNR and that this dependence is linear, i.e., if the voxel volume doubles then the SNR doubles.

In MR imaging, the most common way to increase SNR is to acquire additional signal averages or excitations, effectively collecting more raw data. Unfortunately, due to the nature of MR noise statistics, a doubling of the number of excitations (NEX) only results in a square root 2 increase in the resultant SNR. The well-known relationship is that SNR varies as the square root of the total scan time.

Acceptable clinical protocols are those that simultaneously meet three criteria: SNR, spatial resolution and scan time. Figure 2A is an example of conventional reconstruction. Given a clinically acceptable SNR level, as indicated by the red contour line, any protocol with a larger voxel volume or longer scan time will result in higher SNR. However, the acceptable clinical protocol is also bounded by the clinical spatial resolution threshold (vertical dotted line) and clinical scan time threshold (horizontal dotted line), leaving the only clinical acceptable protocols as being those in the red triangular shaped region in Figure 2A.

We can redraw the protocol space for AIR™ Recon DL to see how the SNR gain and improved image sharpness manifest in the protocol space. As shown in Figure 2B, the SNR contour with AIR™ Recon DL is shifted lower for scan time and voxel volume due to the SNR advantage over conventional reconstruction. To clarify, the red contour in Figure 2A and the blue contour in Figure 2B represent the same clinically acceptable SNR, however, AIR™ Recon DL delivers this with shorter scan times and smaller voxel volumes. Also note the positioning of the clinical resolution threshold (vertical dotted line) as being further to the right on Figure 2B compared to Figure 2A. This reflects AIR™ Recon DL's Intelligent Ringing Suppression that can deliver equivalently sharp images with larger voxel volumes.

AIR™ Recon DL reconstruction allows for an expanded protocol space, or more protocol combinations of voxel

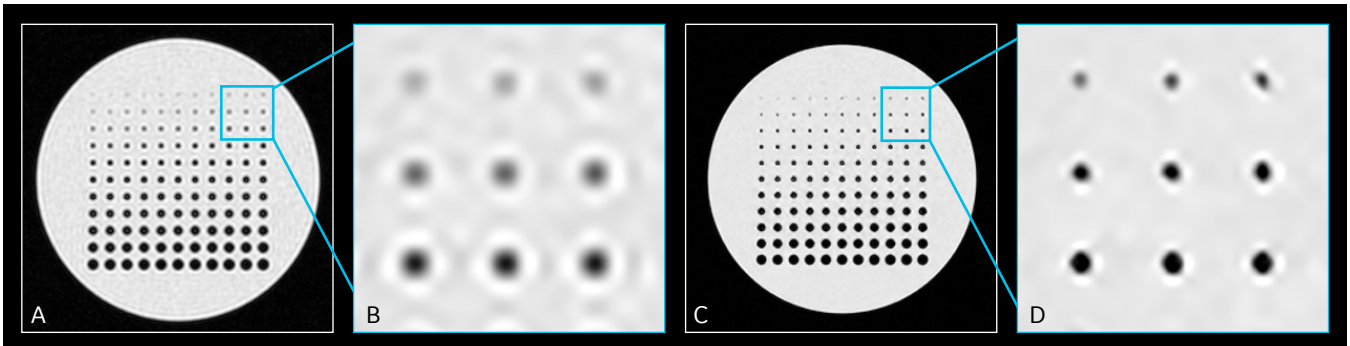

Figure 1. AIR™ Recon DL Intelligent Ringing Suppression for sharper images as demonstrated in an imaging phantom. (A) Conventional image reconstruction with apodization still results in significant Gibbs ringing. (B) Magnified A showing ringing and a loss of fine detail in the circular structures. (C) The same raw data as reconstructed using AIR™ Recon DL shows elimination of Gibbs ringing artifacts and (D) considerably sharper images. Note that the AIR™ Recon DL images also show the added benefit of noise reduction, however, this is considered unrelated to the improved sharpness of the images.

volumes and scan times that are clinically acceptable for SNR, scan time and spatial resolution.

Users have the freedom to select their own level of SNR improvement through a user interface that provides a low, medium or high setting. It is anticipated that, once familiar with the product, users will choose to use the AIR™ Recon DL high setting.

Benefits and early adopter feedback

There are many benefits to AIR™ Recon DL which extend to clinical, operational and financial aspects of MR imaging. Clinical benefits are best demonstrated with images that span multiple anatomies, which compare AIR™ Recon DL to conventional image reconstruction and are shown in Figures 3-6.

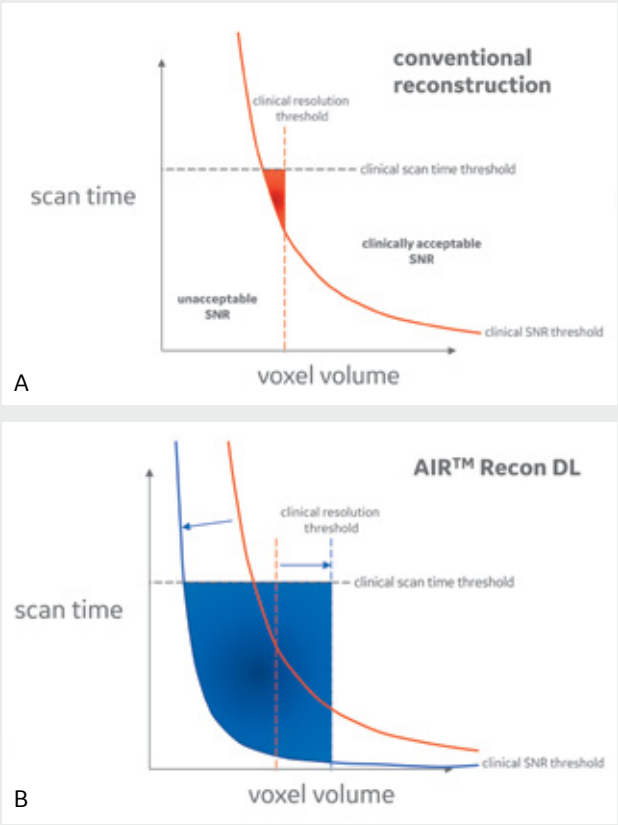

Figure 2. Expanded clinical protocol space with AIR™ Recon DL. (A) Conventional reconstruction with the clinically acceptable SNR contour, as indicated in red, the only protocol combinations of voxel volume and scan time that are simultaneously clinically acceptable for SNR, scan time and spatial resolution is the triangular area in red. (B) An expanded protocol space with AIR™ Recon DL reconstruction showing the clinically acceptable SNR contour to be shifted lower and the clinically acceptable resolution threshold is further to the right, compared to conventional reconstruction in (A, red solid and dotted lines). The area in blue represents more protocol combinations of voxel volumes and scan times that are clinically acceptable for SNR, scan time and spatial resolution with AIR™ Recon DL.

Operationally, it is expected that AIR™ Recon DL will lead to more predictable patient scheduling as a result of fewer repeat scans and shorter scan times. This may also allow for disinfection time between patients during the COVID-19 pandemic. The scan time savings and more consistent image quality may help reduce stress among the MR technologists and radiographers.

Of the thousands of cases collected with both conventional and AIR™ Recon DL reconstructions, no pathologies were reported to have been missed compared to the conventional reconstructed images[§]. In addition, no instances were identified where structures were hallucinated with AIR™ Recon DL.

Anatomical coverage is also a key consideration and can sometimes be dependent on the training of the DL algorithm. AIR™ Recon DL is compatible with all anatomies.

GE provides users the capability to generate the conventional reconstruction images for comparison with AIR™ Recon DL images, which can be useful for establishing clinical confidence during the initial phase of familiarity.

As AIR™ Recon DL makes use of raw data and is integrated in the reconstruction pipeline, it delivers images to the MR

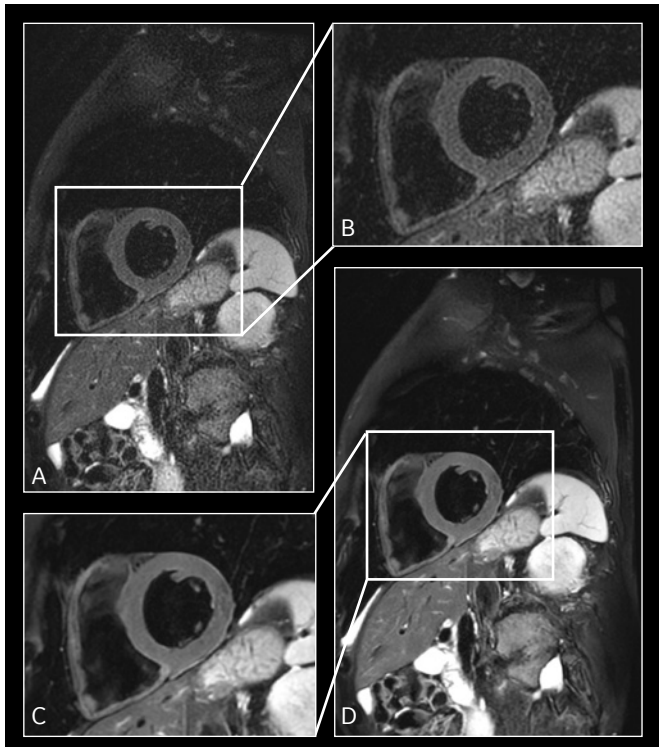

Figure 3. SNR improvement with AIR™ Recon DL. Shown is a short axis T2 Double IR black-blood FatSat breath-hold scan, 1.3 x 1.4 x 6 mm, 2:13 min. scan time with 11 sec. breath hold. (A, B) Conventional image reconstruction and (C, D) AIR™ Recon DL high setting of the same raw data showing considerable SNR improvement.

[§]These cases were not part of the US FDA submission for AIR™ Recon DL.

console in real-time, allowing the MR technologist to assess the image quality while the patient is still on the table.

In summary, AIR™ Recon DL offers many clinical benefits over conventional image reconstruction, including increased SNR and sharper images due to the Intelligent Ringing Suppression, as demonstrated on both phantom and in vivo. Functioning on raw data, AIR™ Recon DL can help users manage the delicate balance between spatial resolution, SNR and scan time. With an understanding of the relationship between SNR, voxel volume and scan time, AIR™ Recon DL can significantly expand the clinically useable protocol space, allowing users more freedom and flexibility in prescribing MR scans to suit their needs.

References

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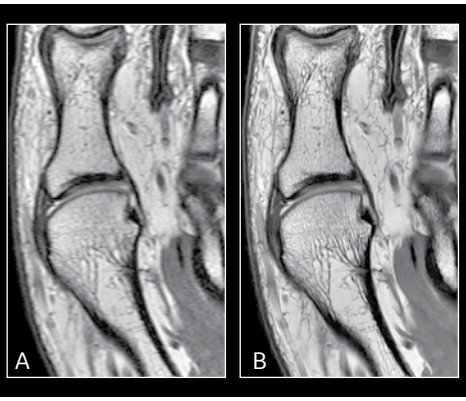

Figure 4. Sharper images with AIR™ Recon DL. Shown is a coronal FSE PDw, 0.3 x 0.3 x 1.0 mm of the first metatarsal. (A) Conventional image reconstruction and (B) AIR™ Recon DL high setting of the same raw data (same matrix and scan time) showing sharper trabecular structure.

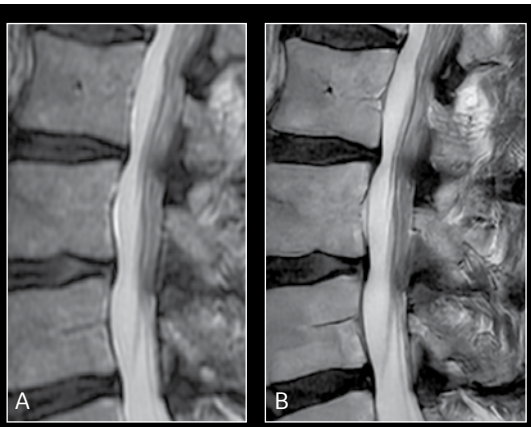

Figure 5. Lumbar spine exam demonstrating (A) conventional reconstructed image, 0.9 x 1.3 x 3 mm, BW 32.2 kHz, NEX 2, 2:47 min. and (B) AIR™ Recon DL reconstructed image, 0.7 x 0.9 x 3 mm, BW 41.7 kHz, NEX 1, 1:16 min.

What early users are saying

21 radiologists from 11 different sites and 6 different countries were asked about their experience using AIR™ Recon DL[‡‡].

100% said:

- Images are sharper and more detailed
- Can enable prescription changes to shorten scan time
- Images display less noise

95% said:

- Improves lesion conspicuity
- Improves diagnostic confidence
- May help reduce the number of repeat series

90% said:

- May allow for prescription changes to increase spatial resolution
- Images are easier to read, can be read quicker and lead to reduced eye fatigue

4 out of 5 radiologists agree

that AIR™ Recon DL will reduce variability across different patients and technologists

[‡‡]Based on an early adopter survey of 21 radiologists from 11 different sites and 6 different countries.

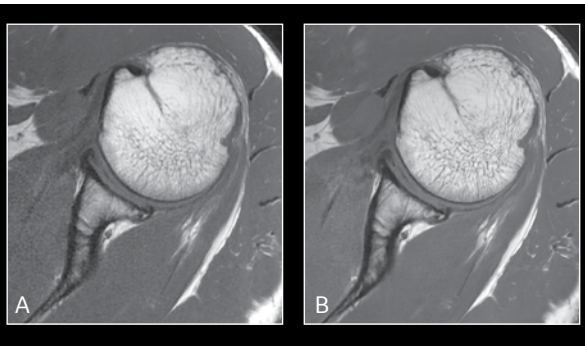

Figure 6. Shoulder exam demonstrating a 46 percent improvement in resolution and a 36 percent reduction in scan time with AIR™ Recon DL. (A) Conventional reconstructed image, 0.4 x 0.6 x 3 mm, BW 41.7 kHz, NEX 1, 2:14 min. and (B) AIR™ Recon DL reconstructed image, 0.3 x 0.5 x 3 mm, BW 62.5 kHz, NEX 1, 1:33 min.

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Dark-blood, phase-sensitive myocardial late enhancement for assessing myocardial viability

by Alexander Hirsch, MD, PhD, Assistant Professor and Principal Investigator of Cardiovascular Magnetic Resonance Imaging, Department of Cardiology/Radiology and Nuclear Medicine, Erasmus MC, University Medical Center Rotterdam, Rotterdam, The Netherlands

For the last two decades, bright-blood late gadolinium enhancement (LGE) cardiovascular magnetic resonance (CMR) has been the standard non-invasive assessment of myocardial viability in patients with suspected and known ischemia[1]. A key clinical question is whether the myocardium is still viable. Based on an inversion recovery (IR) pulse sequence performed after gadolinium contrast administration, late gadolinium enhancement can help distinguish ischemic heart disease by nulling the magnetization level of viable myocardium so that its dark appearance is distinguished from scar tissue, which appears bright. However, the adjacent blood pool can have a similar bright signal, making the border between scar and blood difficult to distinguish and in some cases obscured. This limitation is heightened in cases of thin subendocardial infarction and scarring. Pathology obscured or undistinguishable from the blood pool can result in under reporting of the volume of scar tissue, as well as false negative observations.

To overcome these problems, several dark-blood LGE sequences have been developed to improve the contrast between blood and scar, including a novel sequence from GE Healthcare[2]. However, Holtackers et. al.,[3] proposed a simple, elegant dark-blood approach using a standard phase-sensitive (PS) LGE sequence that can easily be implemented in routine clinical care. This dark-blood approach was found to improve detection of ischemic scar and significantly increased total scar burden compared to bright-blood LGE. The authors also reported significant improvement in image quality and significantly higher observer confidence[4].

The only difference between the regular bright-blood PS LGE and dark-blood approach is the setting of the inversion time. For conventional bright-blood PS LGE, the inversion time is set to null viable myocardium, while for dark-blood PS LGE the inversion time is set to null the left ventricular blood pool. Whichever blood pool contrast is desired, the nulling point can be determined by the Cine IR.

In this article, different examples are shown using a single-shot PS LGE (myocardial delayed enhancement, or MDE, on GE MR systems) sequence and Cine IR on the SIGNA™ Artist 1.5T. The inversion time was shortened from nulling remote myocardium to nulling blood pool signal based on the Cine IR images, so that the blood pool appears as black as possible against the infarct that appears bright. The inversion time is set differently for each patient,

SIGNA™ Artist 1.5T

	Bright-blood PS MDE	Dark-blood PS MDE
Inversion preparation time (ms):	250-350 null viable myocardium	150-250 null the LV blood pool

depending on the amount of contrast, the post-contrast acquisition time and the dynamic of the contrast. Other PS LGE parameters remain unchanged. A prototype of AIR™ Recon DL[‡], a deep-learning-based reconstruction algorithm that improves signal-to-noise ratio (SNR) and image sharpness by making use of the raw data to remove image noise and ringing, was also utilized.

Case 1

Patient history

A 60-year-old male without cardiac history presented with out-of-hospital cardiac arrest. An invasive coronary angiogram showed extensive three-vessel disease. CMR was performed to assess viability and showed a dilated left ventricle with poor systolic function.

Results

Images depict extensive subendocardial infarction in both the right coronary artery and the left anterior descending artery territory. The dark-blood PS MDE image (Figure 1C) shows much better delineation between the blood and subendocardial infarction than the bright-blood images (Figures 1A, 1B).

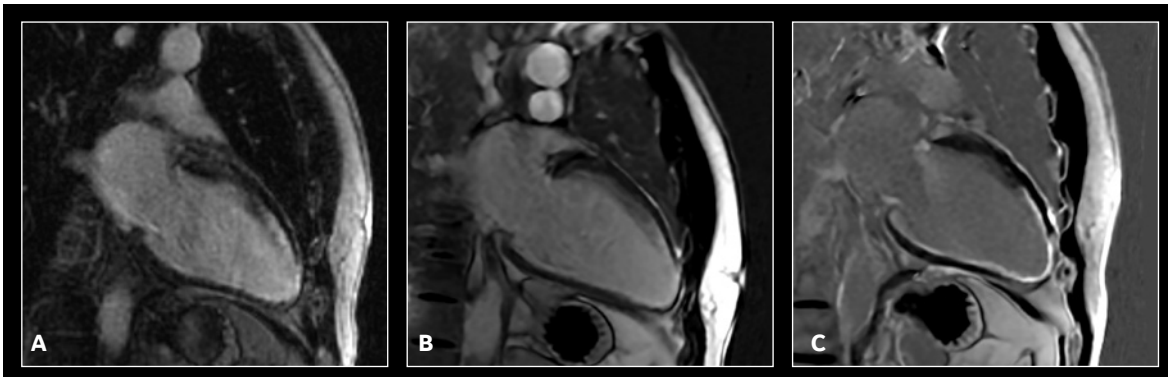

Figure 1. Depicted are two-chamber LGE images with different techniques. (A) Multi-shot bright-blood MDE, (B) single-shot, bright-blood PS MDE with a prototype AIR™ Recon DL (high) and (C) single-shot, dark-blood PS MDE with a prototype AIR™ Recon DL (high).

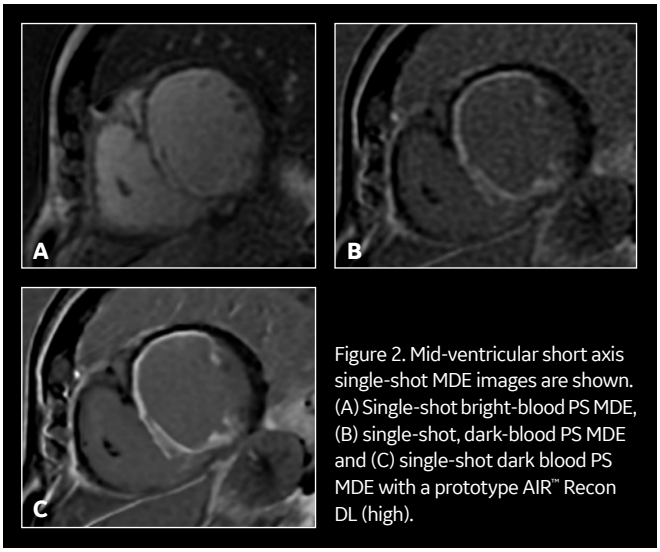

Figure 2. Mid-ventricular short axis single-shot MDE images are shown. (A) Single-shot bright-blood PS MDE, (B) single-shot, dark-blood PS MDE and (C) single-shot dark blood PS MDE with a prototype AIR™ Recon DL (high).

Case 2

Patient history

A 65-year-old male with a history of inferior myocardial infarction was admitted because of heart failure with poor systolic left ventricular function. MR was performed to assess viability after invasive coronary angiogram and helped determine three-vessel disease, including significant left main disease and chronic total occlusion of the right coronary artery and left anterior descending artery. The 2D MDE images were of poor quality because of difficulties with breath-holds (images not shown).

Results

The extensive myocardial infarction is much better visualized with dark-blood PS MDE as shown in Figure 2B, 2C. Also late gadolinium enhancement of the papillary muscle is observed in the dark-blood PS MDE and further enhanced by the prototype AIR™ Recon DL (Figure 2C).

[‡]Not yet CE marked on 1.5T. Not available for sale in all regions.

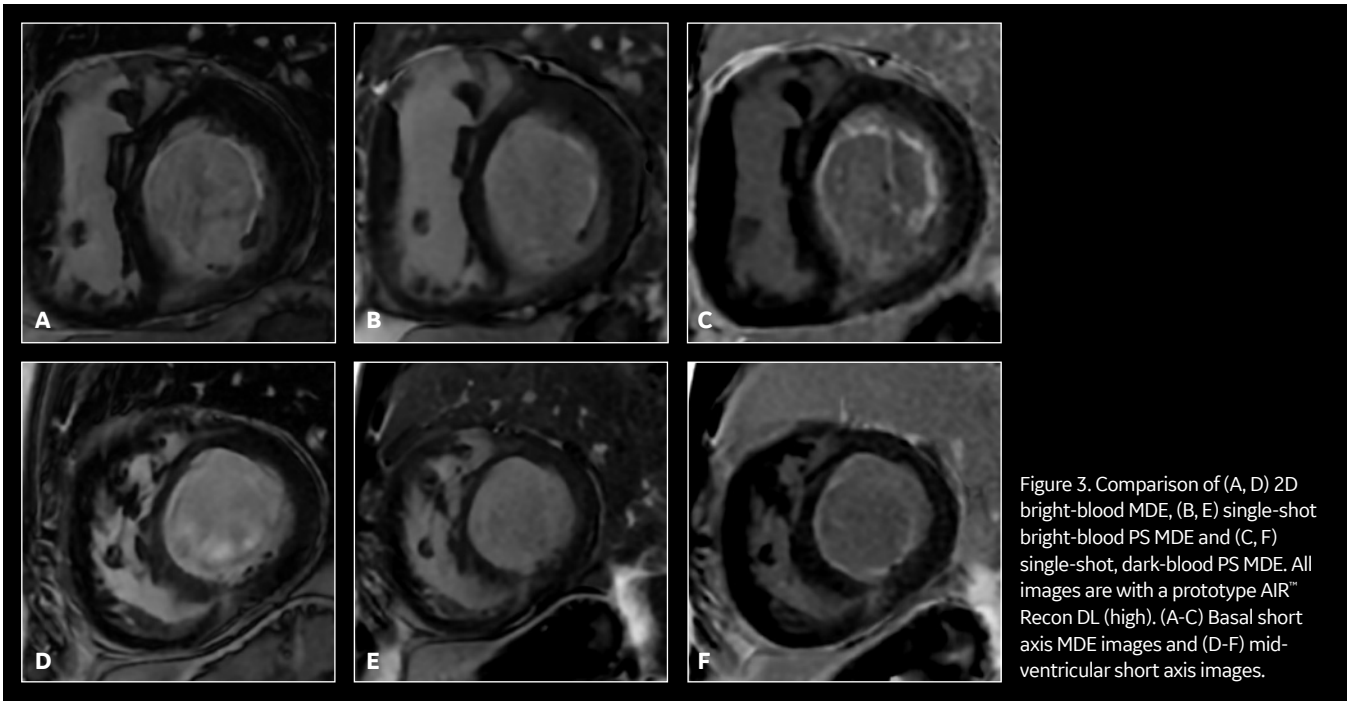

Figure 3. Comparison of (A, D) 2D bright-blood MDE, (B, E) single-shot bright-blood PS MDE and (C, F) single-shot, dark-blood PS MDE. All images are with a prototype AIR™ Recon DL (high). (A-C) Basal short axis MDE images and (D-F) mid-ventricular short axis images.

Case 3

Patient history

This is a rare case of restrictive cardiomyopathy with pulmonary hypertension due to endocardial fibroelastosis in a 20-year-old patient with history of congenital subvalvular and valvular aortic stenosis[5].

Results

There is a thin layer of endocardial late enhancement visible in the left ventricle that is almost circular. This is best recognized in the dark-blood PS MDE images (Figure 3C). In addition to the endocardial late enhancement, there is also focal late enhancement in the inferior right ventricular insertion point.

Discussion

The dark-blood technique with PS MDE and Cine IR facilitates evaluation of myocardial scarring and viability, especially in cases of subendocardial infarction. It is easy to implement and currently available on most MR scanners and, therefore, can be implemented in clinical practice. As demonstrated by Holtackers et. al., the dark-blood PS MDE is more sensitive for detecting ischemic scar, yet it did not impede the ability to detect thrombus.

A single-shot PS MDE typically results in less SNR and more noise compared to segmented breath-hold techniques. However, the addition of AIR™ Recon DL increases overall image quality by neutralizing the increase in noise and boosting SNR[6]. While the addition of AIR™ Recon DL is not a requirement for dark-blood PS MDE, it improves a rapidly acquired scan with high image quality. Further, this reconstruction technique helped highlight the infarct in cases of ischemic heart disease with good contrast between the infarct, the blood and the blood pool.

The combination of single-shot PS MDE for dark-blood imaging and AIR™ Recon DL also enhanced our clinical confidence, although diagnoses were unchanged. Understanding how this technique may impact quantification of the infarct is an area that remains to be studied. Therefore, dark-blood, single-shot PS MDE could be used as a rapid tool in addition to standard PS MDE.

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Assessing damaged myocardium using a novel black blood MDE sequence

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Cardiac MR enables both anatomical and functional assessment of the heart. Black blood (BB), T2 STIR and fat suppression are commonly used for the detection of areas at risk for infarction and scar. In some cases it is difficult to differentiate between scar and blood pool using late gadolinium enhancement (LGE) sequences. In particular, factors such as the volume of gadolinium-based contrast, clearance rate and the timing of the LGE acquisition contribute to the similar signal intensity of the blood pool and the area of infarct. To overcome this, usually we compare cine images and LGE images in the same cardiac phase of acquisition.

The availability of BB LGE sequences makes it easier to depict subendocardial infarction, as well as involvement of the papillary muscles with higher contrast-to-noise ratios. We evaluated GE Healthcare's BB myocardial delayed enhancement (MDE)[†] sequence for research purposes in 73 patients with known or suspected coronary artery disease who underwent a cardiac MR exam.

Patient history

A 53-year-old patient weighing 52 kg (115 lbs.) for evaluation of acute myocardial infarction.

MR findings

Cardiac MR shows a subendocardial myocardial infarction with 50-100 percent of transmurality in inferoseptal, inferior segment of the middle-ventricle myocardium and apical septum (Figure 1A). The findings were confirmed on BB MDE images (Figure 1B).

Discussion

The BB MDE sequence enabled us to depict the subendocardial enhancement and involvement of papillary muscles, and clearly distinguish the damaged myocardium from the blood pool activity. This capability may be especially useful in cases where the standard LGE sequence is non-diagnostic.

In particular, the possibility to have a dark blood in both ventricles with the BB MDE sequence is extremely promising. Overall, the image quality was good, providing excellent diagnostic capability.

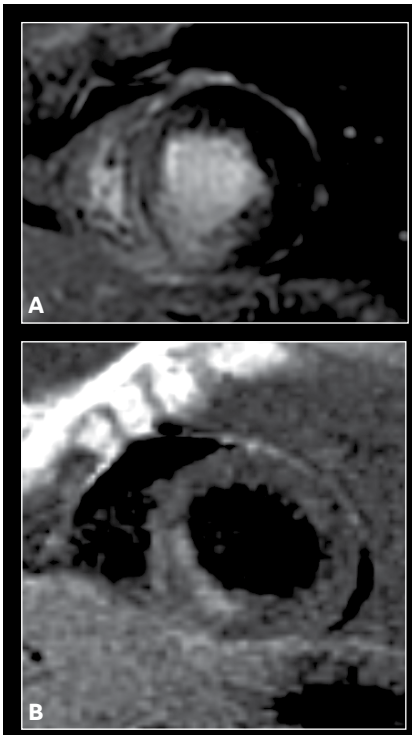

Figure 1. A 53-year-old patient with acute myocardial infarction on territory of right coronary artery. (A) Short axis shows subendocardial late gadolinium enhancement of inferior and inferoseptal myocardial segments. The findings were confirmed on (B) BB MDE images.

[†]Technology in development that represents ongoing research and development efforts. These technologies are not products and may never become products. Not for sale. Not cleared or approved by the US FDA or any other global regulator for commercial availability.

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CMR for assessing coronary structure and function after myocardial infarction

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Cardiovascular disease (CVD) is a national health issue in South Africa, with cardiovascular disease being the country's second-leading cause of death behind HIV and AIDS. Patients living with HIV are at an increased risk for CVD with antiretroviral therapies, and in particular protease inhibitor-based regimens, further increasing their risk[1].

Cardiac MR (CMR) is now regarded as a very important tool in the diagnosis and management of CVD in South Africa[2] as a result of efforts led by the Radiological Society of South Africa, including the development of the South African Cardiac Imaging Society subcommittee. CMR provides high spatial resolution, image contrast and tissue characterization, making it indispensable for evaluating ventricular size and function of the left and right ventricles. It can also help clinicians differentiate ischemic heart disease and non-ischemic cardiomyopathies.

Proper diagnosis of CVD with CMR not only enhances the quality of care, but it can help the clinician determine prognosis, the need for additional tests and appropriate treatment or therapeutic procedures.

Recent advances in CMR have led to the development of techniques for non-invasive assessment of cardiovascular structure and function. In particular, myocardial delayed enhancement (MDE) and phase-sensitive (PS) MDE are invaluable sequences. Cine IR is used to determine the optimal inversion recovery time (TI). With PS MDE, the TI evolution image can help us detect certain tissue T1 abnormalities such as myocardial viability, cardiomyopathy, myocarditis and other infiltrative myocardial processes.

In late 2017, our facility upgraded its Optima™ MR360 system to SIGNA™ Voyager, which has a 70 cm bore, Total Digital Imaging (TDI) technology, high performance gradients with 36 mT/m amplitude and a 150 T/m/s slew rate.

Patient history

A 56-year-old male suffered an anterior myocardial infarction. PET and myocardial perfusion scintigraphy studies provided conflicting results. In the PET exam, a large perfusion defect was noted in the apex, anterior wall and apical aspect of the inferior wall; the apex of the left ventricle had an aneurysm appearance and questionable myocardium viability. The scintigraphy exam demonstrated a large fixed perfusion defect involving the anterior wall, apex and inferoapical aspect of the left ventricle; results indicated the possibility of an aneurysm and dilated cardiomyopathy.

The patient was referred to CMR to address the conflicting results from the PET and scintigraphy studies and assess the viability of the myocardium.

SIGNA™ Voyager

	FGRE Time Course	*Cine IR*	*T2 DIR FatSat*	*MDE 2D 2RR*	*4 chamber MDE*	*Short axis PS MDE stack*	*Left ventricular outflow tract*
TR (ms):	2.9	4.6		3	3.2	7.6	3.5
TE (ms):	min full	min full	56	1.3	1.4	min full	min full
FOV (cm):	36 x 28.8	38 x 30.4	36 x 36	38 x 30.4	30 x 27	38 x 34.2	28 x 28
Slice thickness (mm):	10 with 19 spacing	10	10	10	8	8 with 1 spacing	6
Frequency:	128	80	200	160	160	224	128
Phase:	84	80	192	140	140	140	60
NEX:	1	1	1	1	1	1	1
Scan time (sec.):	60	13	60	6	27	120	14
Options/other (b value, no-phase wrap, etc.):	5 slices	1 slice	6 slices	Prep time 350; 1 slice	Prep time 350; 9 slices	Prep time 350; 10 slices	1 slice

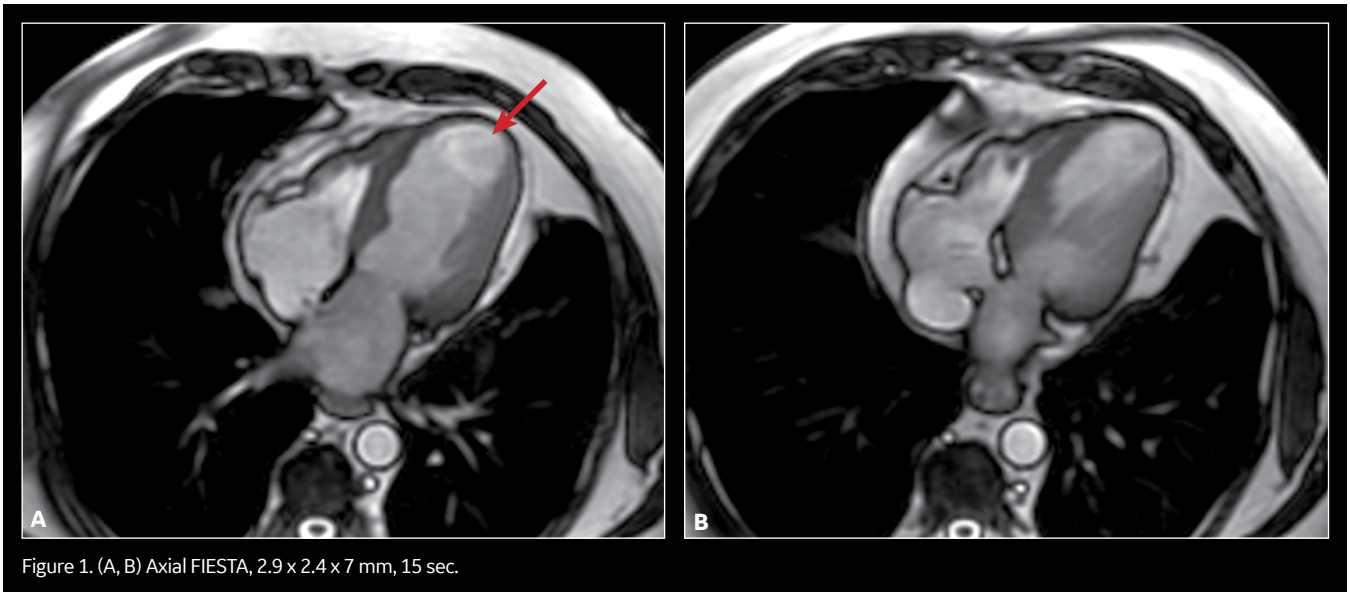

Figure 1. (A, B) Axial FIESTA, 2.9 x 2.4 x 7 mm, 15 sec.

MR findings

CMR showed aneurysm dilatation and ballooning of the apex with thinning of the left ventricle myocardium (5-6 mm) and decreased perfusion of the left ventricle during rest (Figure 2). Post-contrast subendocardial enhancement of the apex and anterior segment of the left ventricle with 50 percent involvement (Figure 3). Enhancement is most likely due to subendocardial ischemia in the left anterior descending artery territory with a viable myocardium. Functional analysis showed an ejection fraction of 33 percent indicating left ventricle function impairment.

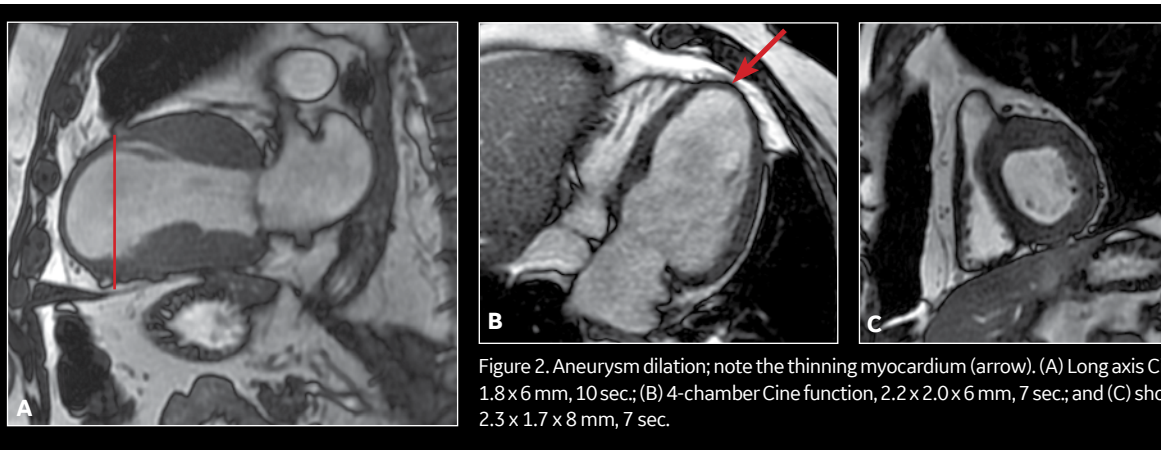

Figure 2. Aneurysm dilation; note the thinning myocardium (arrow). (A) Long axis Cine FIESTA, 2.2 x 1.8 x 6 mm, 10 sec.; (B) 4-chamber Cine function, 2.2 x 2.0 x 6 mm, 7 sec.; and (C) short-axis Cine stack, 2.3 x 1.7 x 8 mm, 7 sec.

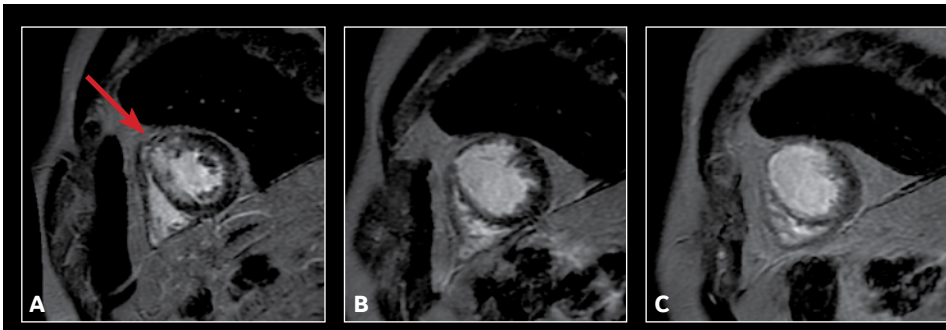

Figure 3. (A-C) Short-axis PS MDE acquisition demonstrates subendocardial enhancement of the apex and apical anterior segment of the left ventricle with 50 percent involvement (arrow). Parameters: 1.7 x 2.4 x 8 mm, 9 sec.

Discussion

The SIGNA™ Voyager provided the image quality needed so we could visualize the difference between normal and diseased tissue. The 2D FIESTA/FGRE Cine pulse sequence provides excellent blood-to-myocardium contrast. Short TR/TE allows for the acquisition of high-quality cardiac images that are less sensitive to turbulent blood flow and off-resonance artifacts. The FGRE Time Course (TC) performs fast, robust cardiac studies that enhance our clinical confidence. FGRE TC also delivers excellent temporal and spatial resolution and T1 contrast to aid in a more confident diagnosis of the myocardium. 2D/3D MDE helps us to determine myocardial tissue viability fast, simply and reliably, and assess fibrosis by improving the contrast-to-noise ratio between an infarct and normal myocardium.

With CMR, we can provide a non-invasive technique to evaluate the structures and function of the heart to help guide patient management, therapy and interventions.

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A 10-minute comprehensive cardiac MR exam with flow quantification

By Rashid Al Umairi, MD, FRCR, FSCMR, cardiothoracic radiology consultant, The Royal Hospital, Muscat, Oman

Aortic valve regurgitation, also known as aortic valve insufficiency or aortic valve incompetence, is a valvopathy that describes leaking of the aortic valve during diastole that causes blood to flow in the reverse direction from the aorta and into the left ventricle. Patients with valvular conditions are referred to MR following an inconclusive Doppler ultrasound exam. While Doppler ultrasound is the current gold standard, it cannot always provide a precise answer on whether the patient should undergo surgery in cases with a poor acoustic window.

A cardiac MR (CMR) exam is comprised of various sequences that can provide a detailed assessment of the aortic valve and left ventricular function. It is a highly accurate method to determine the size of the aortic root, assess regurgitant parameters, determine ejection fraction, measure left ventricular size and detect underlying etiologies. However, acquiring quality cardiac sequences to quantify cardiac function and flow has historically been a complex and time-consuming exam to perform, requiring technologist expertise and physician supervision with little room for error when capturing constantly moving anatomy. Conventional CMR techniques like 2D phase contrast require multiple slice acquisitions that are perpendicular to the flow of the blood. For some pathologies, this would require the patient to hold their breath — in many cases greater than 20 times in an exam. Considering that patients who typically receive a CMR exam often have heart disease, it can be difficult for them to repeatedly hold their breath and, therefore, exams may suffer from sub-optimal or non-diagnostic image quality. Despite the value of CMR, these limitations continue to complicate image acquisition.

New technology could shift this paradigm. Several techniques enabling free-breathing flow acquisitions are under investigation. Real-time CMR is one approach to image acquisition during free-breathing that is analogous to echocardiography, or cardiac ultrasound. Using acceleration techniques, the data is rapidly acquired throughout the breathing cycle and then reconstructed to provide an average heartbeat. Alternatively, 3D CMR data can be acquired during free-breathing over several minutes using respiratory motion compensation, with data then reconstructed retrospectively.

To improve data acquisition in our institution, we have implemented the ViosWorks 4D Flow sequence in standard CMR exams. With this technique, the

SIGNA™ Artist

PARAMETERS		
	4D Flow	*FIESTA Cine*
TR (ms):	4.7	3.8
TE (ms):	2.14	Min Full
FOV (cm):	36	38
Slice thickness (mm):	2.2	8
Frequency:	170	200
Phase:	170	192
NEX:	4	1
Scan time (min):	7:25	0:09
Options/other (b value, no-phase wrap, etc.):	ZIP2	

Figure 1. cvi42® post-processing for streamlined visualization.

technologist simply places the imaging volume over the patient's chest and data acquisition is completed with no breath-holds. There is little interaction necessary on the front end and immediate reconstruction of the images in order to review instantly, which is helpful to ensure the proper velocity encoding (VENC) of the vessel before the patient gets off the table. The image can be reformatted to an arbitrary plane and blood flow in the entire volume can be quantified retrospectively in offline processing.

The 4D Flow data can be used to measure blood flow velocity and direction in any part of the cardiovascular system, including flow quantification in the ascending aorta and main pulmonary artery, as well as in patients with congenital heart disease. This approach is particularly attractive because these patients frequently require flow measurements to be made in multiple vessels and at various levels within that vessel. Using traditional 2D CMR sequences, flow in each location is measured from a separate acquisition that needs to be set up precisely from separately acquired localizer images, resulting in prolonged scan times.

With ViosWorks 4D Flow, the volume of data is enough to cover the entire chest. Isotropic images are gated and timed to the breathing cycle to provide high spatial resolution with 2 mm^3 slices, enabling retrospective reformatting in any image orientation.

Patient history

A 24-year-old male with an unremarkable medical history presented with recurring shortness of breath on exertion. On auscultation, the patient was found to have a heart murmur. He was referred for further assessment with echocardiogram, which revealed severe aortic regurgitation with dilated left ventricle and systolic dysfunction. The patient underwent CMR for an accurate measurement of aortic regurgitation and to investigate the cause of left ventricle dilatation.

Technique

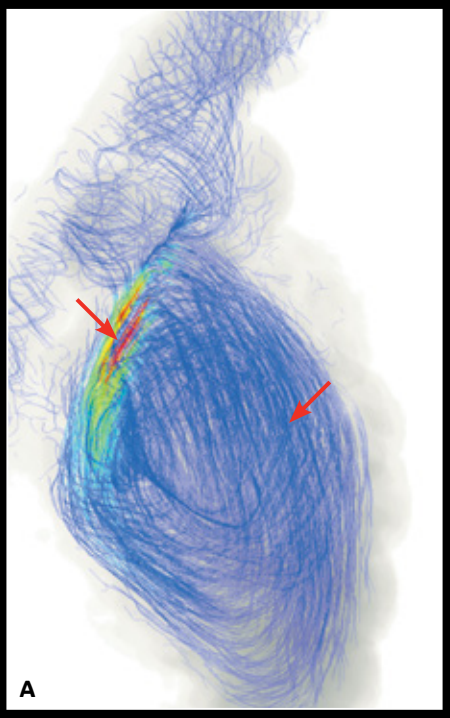
The ViosWorks 4D Flow sequence was performed on a 1.5T SIGNA™ Artist and was completed in as little as 10 minutes with the patient free-breathing. This technique provides quantitative cardiac measurements including flow, regurgitant fraction, stroke volume, ventricular volumes and ejection fraction.

MR findings

Patient diagnosed with bicuspid aortic valve, a congenital disorder, and vortex, or twisted, flow.

Aortic flow (obtained by analyzing 4D Flow):

- Total forward volume: 93 ml
- Backward volume: 35 ml
- Forward volume: 58 ml
- Regurgitation fracture: 38%



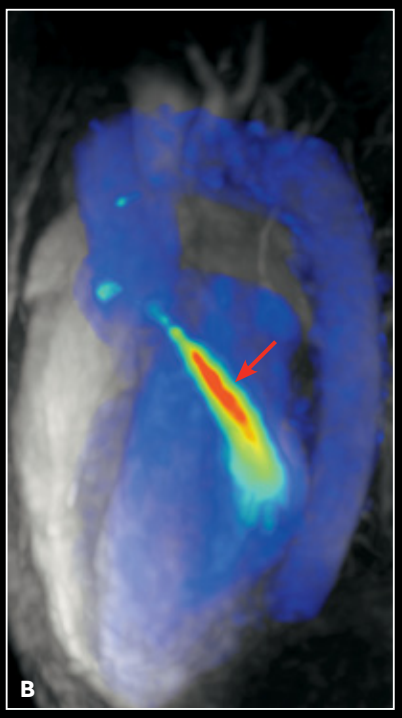
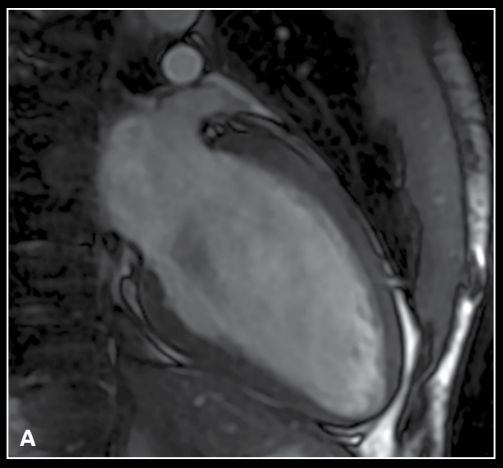


Figure 2. Using cvi42® it is possible to detect regurgitation flow (arrows).



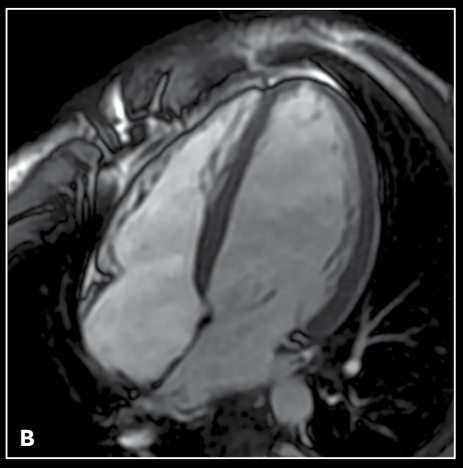


Figure 3. (A) 2-chamber FIESTA Cine and (B) 4-chamber FIESTA Cine.

Left ventricle function and volume:

- Ejection fraction: 60%
- LVEDV/BSA: 141 ml/m^2 (dilated)

ViosWorks 4D Flow provided a complete view of anatomy of the heart, including the flow within the four chambers and large vessels. This allowed us to study flow patterns throughout the cardiac cycle and to visualize turbulences and quantify flows such as regurgitations. As a result, we were able to diagnose vortex, or twisted flow, which is a blood flow that has separated from the central streamlines within a vessel and countercurrent to the main flow direction. This condition was only diagnosed by using 4D Flow and was not seen on conventional 2D phase contrast or echocardiography.

Discussion

The 4D Flow technique provides the information needed for basic flow quantification and appears promising for more advanced hemodynamic analysis, including pressure gradients, wall shear stress, pulse wave velocity and kinetic energy. It delivers high-resolution images depicting volumetric, cardiac-motion-resolved heart anatomy and blood flow with improved exam efficiency and minimal or no breath-holding, addressing many of the challenges facing CMR today. With ViosWorks, for the first time all seven dimensions of information — 3D in space, 1D in time and 3D in velocity — can be captured in a 10-minute or less free-breathing cardiac exam.

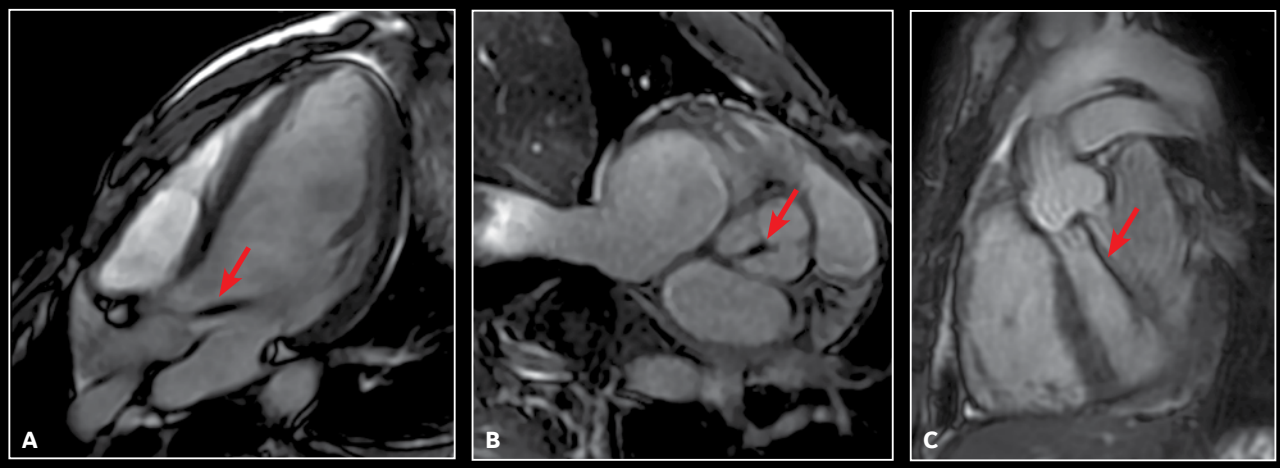


Figure 4. (A) 3-chamber LVOT FIESTA Cine for evaluating function; (B) short axis FIESTA Cine; and (C) sagittal oblique FIESTA Cine perpindicular to the aortic valve demonstrating the flow jet from regurgitation.

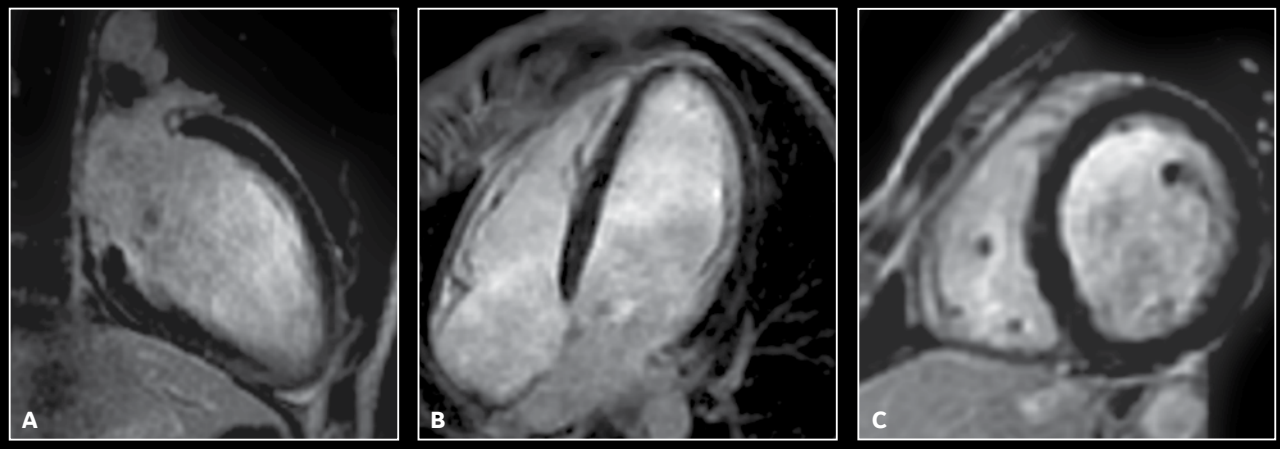


Figure 5. (A) 2-chamber, (B) 4-chamber and (C) short axis PS MDE, post-contrast.

ViosWorks 4D Flow has enabled us to accurately measure trans-stenotic pressure gradients non-invasively in aortic coarctation. Previously, this could only be measured invasively in the cardiac catheterization lab.[1] It may also be possible to identify alterations in hemodynamics that can affect the growth of aneurysms or development of atherosclerotic plaque.

As important, 4D Flow has simplified image acquisition and reduced overall exam time in patients with congenital and valvular heart disease. The use of an acceleration technique has played a significant role in reducing scan time by exploiting data correlations in space. Prescription of the image plane is important to obtain a true double oblique image. Otherwise it is possible for the flow data to be incorrect. Further, a key benefit of 4D Flow is that it acquires comprehensive flow data for the entire data set. We can then go back and process the data retrospectively; if a clinical question is raised after the exam, we can go back and perform additional measurements and process additional flow information from the vessel in the field of view without rescanning the patient.

We are also using the Circle cvi42® post-processing software based on deep learning for faster image analysis. What once took hours of computer processing time now can be accomplished in minutes. Today, ViosWorks 4D Flow is preferred clinically at The Royal Hospital Muscat. 4D Flow is a technology that may change our cardiac imaging practice and we are convinced that this technique will play a more important role in the near future for evaluating patients with cardiac disease.

Reference

1. Fusman B, Faxon D, Feldman T. Hemodynamic rounds: Transvalvular pressure gradient measurement. Catheter Cardiovasc Interv. 2001 Aug;53(4):553-61.

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Detecting ischemia-induced cardiac fibrosis with phase sensitive MDE

By Abdelhamid Derriche, MD, site radiologist, and Orkia Ferdagha, MR technologist, PRIISM, EHP Kara

In cardiac patients, particularly those who have a history of ischemia, determining myocardial viability is critical for planning the patient care pathway as it allows us to identify patients who would not benefit from angioplasty. Myocardial delayed enhancement (MDE) sequences are typically employed for these studies.

A strong saturation of healthy myocardium signal on MDE sequences allows for a better delineation and assessment of ischemic induced cardiac fibrosis. However, the most optimal inversion time value (TI) is needed for acquiring a reliable and clinically useful MDE study. Cine IR allows us to obtain this value even though the TI time continually changes as the contrast washes out.

The introduction of a phase sensitive MDE (PS MDE) sequence now allows for better suppression of healthy myocardium signal even with non-optimal TI values. Additionally, we can avoid rescanning patients in cases of poorly suppressed healthy myocardium signal due to incorrect TI value selection by only evaluating the PS MDE sequence (see Figure 1).

SIGNA™ Explorer

PARAMETERS	*FIESTA Gated Cine SA*	*FIESTA Gated Cine LA*	*FIESTA Gated Cine 4 chambers*	*FIESTA Gated Cine LVOT*	*Tagging SA*	*Perfusion, multi planes in SA + 4 chambers*	*2D MDE SA*	*2D MDE 4 chambers*	*2D MDE LA*	*PS MDE SA*
TR (ms):	4.3	4.3	4.1	4.3	5	3.3	4.9	4.8	4.7	7.6
TE (ms):	1.9	1.9	1.8	1.9	2.3	1.6	1.4	1.4	1.3	3.5
FOV (cm):	38	38	38	38	40 x 28	38 x 34.2	40 x 36	40 x 36	40 x 36	38 x 34.2
Slice thickness (mm):	8	8	8	8	8	10	9	9	9	9
Frequency:	224	224	224	224	256	128	224	224	224	200
Phase:	224	224	224	224	192	96	160	160	160	192
NEX:	1	1	1	1	1	0.75	3	3	3	1
Scan time (min):	1:15	1:17	1:09	0:19 (sec.)	1:49	1:04	2:06	1:59	2:11	2:00
Options / other:							After 8 min. of contrast bolus			After 25 min. of contrast bolus

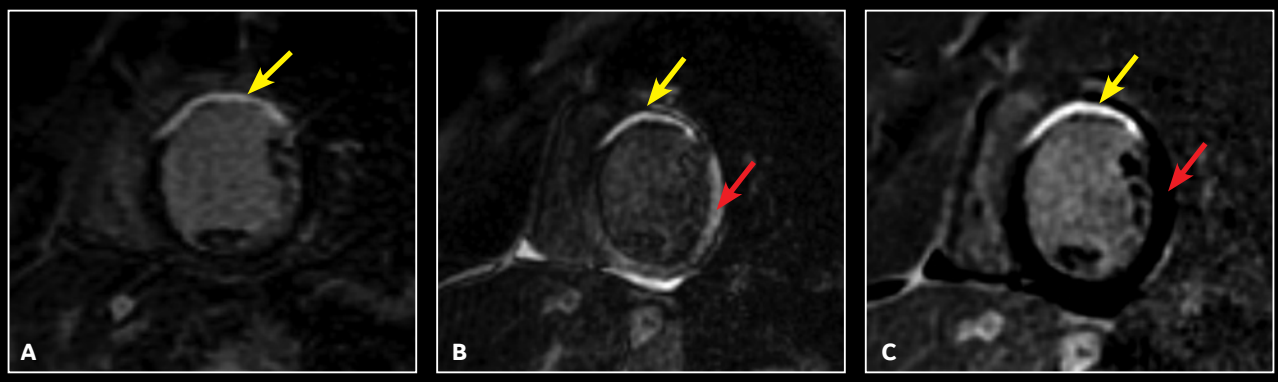

Figure 1. Comparison of 2D MDE and PS MDE. PS MDE provides better visualization of the fibrosis and better suppression of healthy myocardium signal even with non-optimal TI values. (A) 2D MDE SA, 2:06 min; (B) magnitude PS MDE; (C) phase PS MDE SA. Yellow arrows indicate ischemia induced fibrosis; (B-C) red arrows depict a healthy myocardium signal not suppressed on magnitude PS MDE with sub-optimal TI value; using the phase sensitive image from the same acquisition helped to fix this issue.

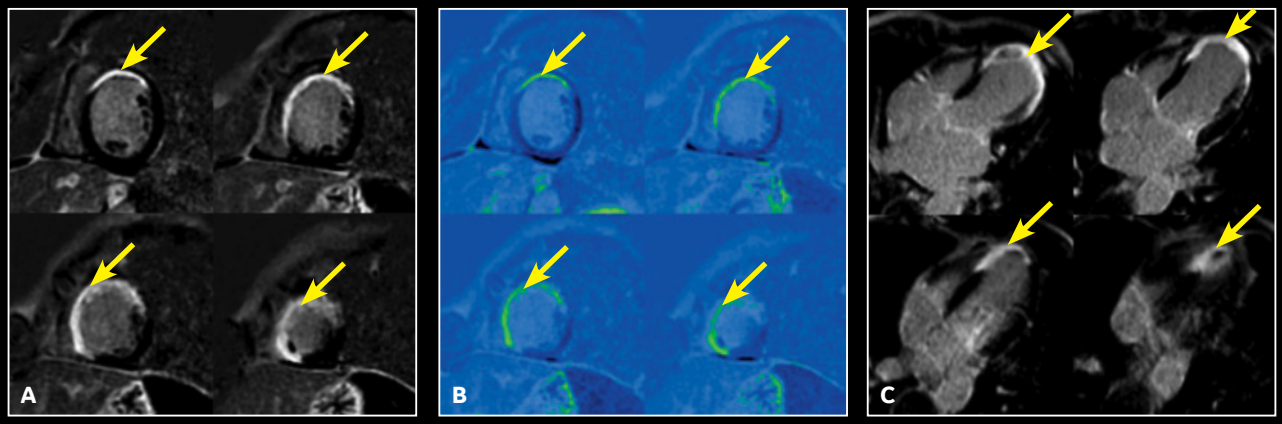

Figure 2. Myocardial viability study. (A, B with color map) 2D PS MDE SA, 1:59 min.; and (C) 2D MDE 4 chambers, 2 min. Yellow arrows indicate ischemia-induced fibrosis.

Patient history

A 60-year-old male with a history of cardiac ischemia referred for a myocardial viability MR exam including function, perfusion and the qualitative analysis of the myocardial viability. The patient has ischemia-induced fibrosis on diseased heart tissues.

MR findings

The left ventricular (LV) function study provides an estimated fractional ejection of 24% and depicts a diffuse akinetic apical contraction with midventricular hypokinesia with anteroseptal predominance.

Perfusion study shows an anomaly with delayed and reduced contrast enhancement with predominance on the subendocardial antero-septo-lateral midventricular region.

MDE demonstrates a systematic myocardial fibrosis belonging to the left anterior descending (LAD) coronary territory (see Figure 2). With contrast uptake we found:

- Transmural on apical anteroseptal;
- Transmural on midventricular septal;
- Inferior to 50% of myocardial thickness on subendocardial anterior midventricular region;
- Sub-endocardial no-reflow phenomenon on the infero-septal region of the apex (also observed on perfusion sequence);
- No regional myocardial parietal thinning of less than 6 mm.

Patient underwent angioplasty and recovered some cardiac function.

Discussion

Using PS MDE, it was possible to assess myocardial necrosis with systematized transmural fibrosis on the LAD coronary territory in the apical anteroseptal region and midventricular septal region as non-viability criteria. Additionally, we determined myocardial ischemia

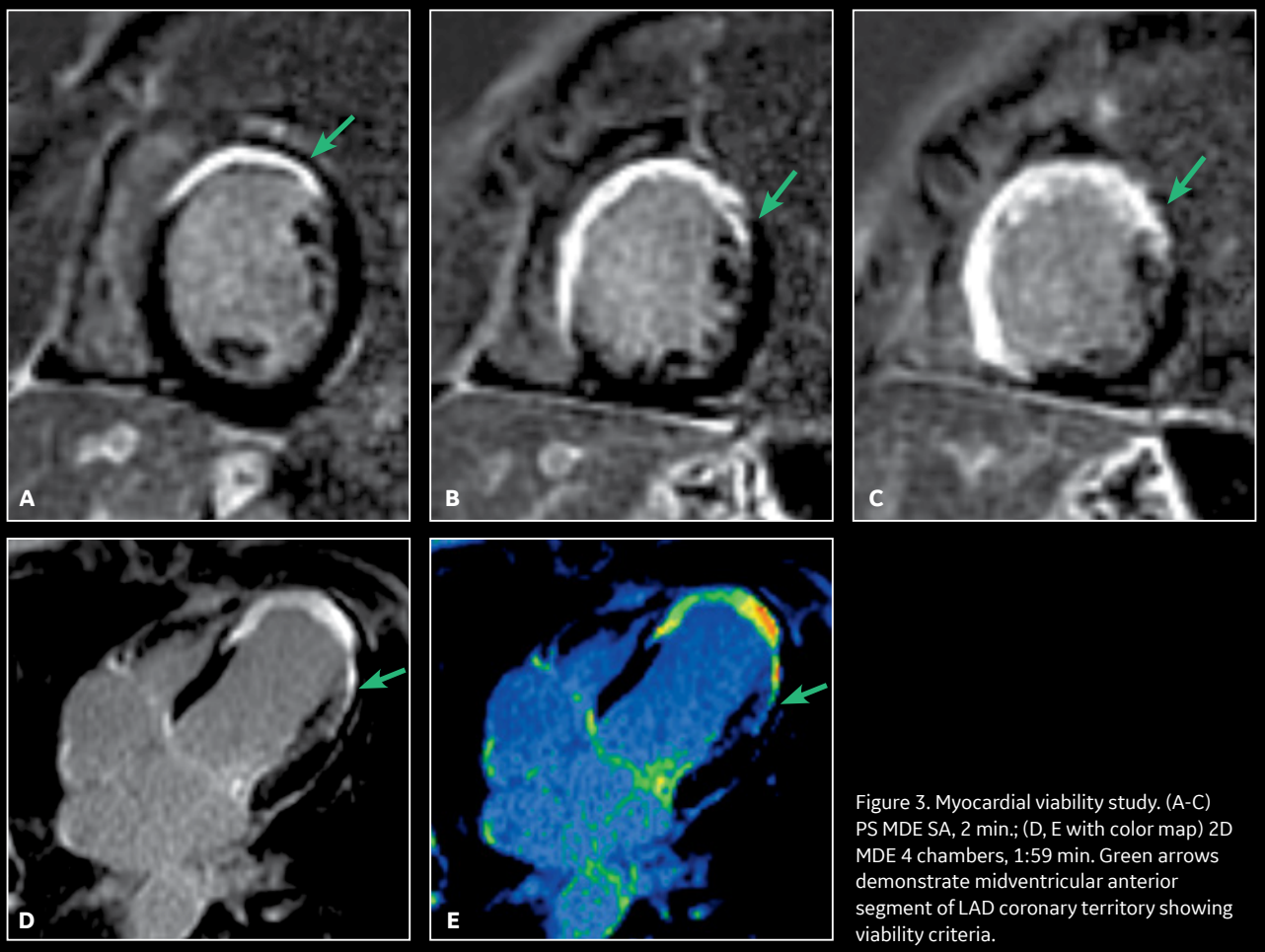

Figure 3. Myocardial viability study. (A-C) PS MDE SA, 2 min.; (D, E with color map) 2D MDE 4 chambers, 1:59 min. Green arrows demonstrate midventricular anterior segment of LAD coronary territory showing viability criteria.

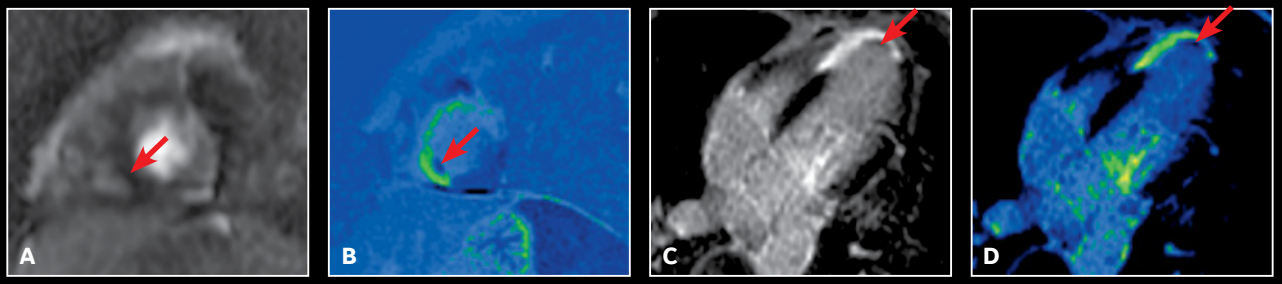

Figure 4. (A) Perfusion FGRE TC SA, 1:04 min.; (B) PS MDE SA with color map, 2 min.; and (C, D with color map) 2D MDE 4 chambers, 1:59 min. Red arrows show the sub-endocardial no-reflow phenomenon on the inferoseptal region of the apex.

with subendocardial fibrosis inferior to 50% of parietal thickness of the anterior segment of the midventricular region with viability criteria as well as hypokinesia of apical and midventricular regions with diminution of LV fractional ejection.

Cardiac MR (CMR) brings a new level of detail and depth to our diagnosis and management of coronary disease. In particular, it supports management of hypertrophic cardiomyopathy patients and post-operative follow-up in Tetralogy of Fallot cases. With CMR and an advanced 1.5T MR system such as SIGNA™ Explorer, we have higher clinical confidence due to excellent imaging capabilities that assists us in myocardium viability studies as well as diagnosing difficult-to-detect conditions, such as myocarditis and arrhythmogenic right ventricular dysplasia. CMR on the SIGNA™ Explorer adds real value to patient care.

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Diagnosing focal myocardial hypertrophy in a 15-minute cardiac MR exam using ViosWorks

By Vicente Martinez de Vega, MD, Head of Diagnostic Imaging Service, University Hospital Quiron Salud Madrid, Spain

Optima™ MR450w GEM

PARAMETERS	*4D Flow*	*3D 2 Slabs*
TR:	4.1 ms	4.4 ms
TE:	2.1 ms	2.1 ms
FOV:	42 cm	40 cm
Bandwidth:	62.5	125
Slice thickness:	2.4 mm	8 mm
Frequency:	172	200
Phase:	172	200
Flip angle:	14	65
ARC acceleration:	Phase x 1 Slice x 1	Phase x 1 Slice x 1
Velocity encoding:	250-350	
Hyperkat:	x 8	x 8
NEX:	4	1
Overlap loc:		0
Locs per slab:		10

Introduction

A comprehensive cardiac MR (CMR) study routinely requires inclusion of cardiac volume measurements and global/segment cardiac function. However, this type of patient exam can be very lengthy to acquire the necessary information—often 60 to 90 minutes requiring 20 to more than 50 breath-holds. In some cases, this can also lead to suboptimal imaging results as many patients undergoing CMR may be acutely ill and unable to remain still and hold their breath throughout the study.

Typically, a CMR exam will include 2D FIESTA sequences in short axis to determine left ventricular function and remodeling fraction and stroke volume; information on the blood flow acceleration in the left ventricular outflow tract using 2D phase-contrast sequences; and delayed, or late, enhancement to detect the presence of fibrosis as well as characterize a wide range of ischemic and non-ischemic cardiomyopathies.

One aspect of a CMR exam that consumes the most time is obtaining white blood images to assess morphology and function using 2D FIESTA sequences acquired in short axis. Replacing this scan with a short axis 3D acquisition acquired in one or two breath-holds is very important as it can save a significant amount of time. For example, scan time of a typical 2D Cine acquisition is 8-10 minutes. In this particular patient case presented below, the 3D Cine scan time was 39 seconds to acquire two slabs, representing a scan time reduction of approximately 92%.

Post-processing of CMR imaging data is another time-intensive process. However, by using the cloud-based, deep learning segmentation of ViosWorks, powered by Arterys™, we can significantly shorten the time needed to review and correct the segmentation. Typically, viewing and correction time of 3D Cine using ViosWorks is less than one minute. In the case presented, the total time spent viewing and correcting the automatic segmentation was 2:15 min due to the complexity of the hypertrophy cardiomyopathy requiring a greater degree of manual correction.

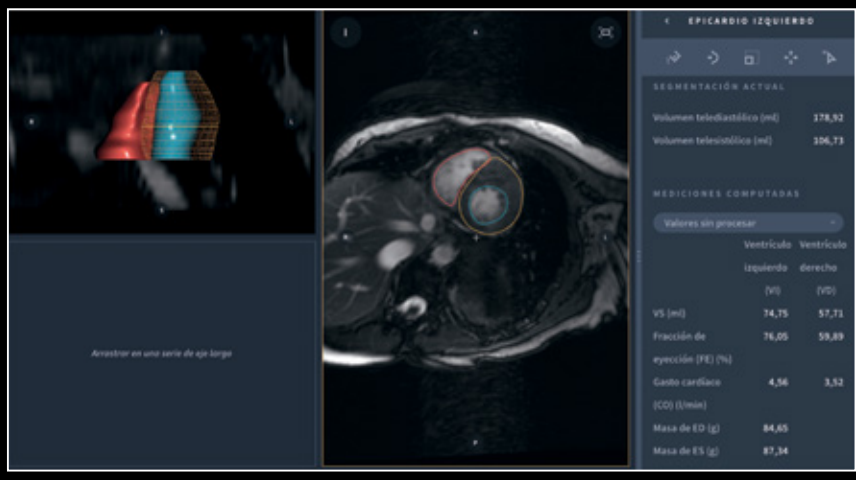


Figure 1. ViosWorks can significantly shorten the time needed to review and correct the segmentation in CMR exams.

Acquisition and processing time

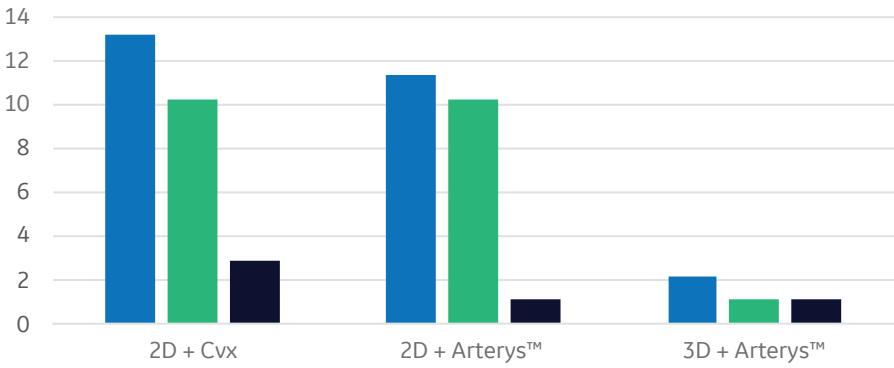


Figure 2. A comparison of (1) 2D Cine scan time + time needed to review and correct ViosWorks segmentation with (2) 3D Cine acquisition time + time needed to review and correct ViosWorks segmentation. 3D Cine with deep learning segmentation leads to shorter examination and analysis time.

Patient history

A 35-year-old patient presented with a complaint of palpitations. ECG indicated arrhythmias and a prior echocardiography exam demonstrated a focal hypertrophic cardiomyopathy affecting the anteroseptal basal region with left ventricular outflow tract obstruction. Anterior displacement of the mitral apparatus and systolic anterior motion (SAM) of the mitral anterior leaflet was also noted.

A CMR exam was indicated for the evaluation of myocardial hypertrophy and areas of fibrosis (using late enhancement).

Protocols used

A fast CMR exam was performed in less than 15 minutes with ViosWorks. The exam included:

- Real-time planning
- 3D Cine short axis
- 4D Flow after intravenous
- contrast injection
- Late enhancement (single shot)

MR findings

The 3D Cine short axis sequence, in a scan time of 39 seconds, provided a left ventricular ejection fraction of 75% and a left ventricular stroke volume of 74.75 ml/beat.

With an acquisition time of 6:30 minutes, the 4D Flow sequence provided a gradient pressure of 29 mmHg with eccentric jet flow in the tubular ascending aorta with turbulent flow. Diameter of the aorta was measured at 31 mm.

The single-shot late enhancement sequence consisted of a short axis acquired in 34 seconds and a long axis acquired in 34 seconds. An intramural enhancement was detected inside the hypertrophic myocardium consistent with the presence of fibrosis.

Total CMR scan/acquisition time: 7:37 minutes.

Ventricular function analysis, scan time and processing time: 2:10 minutes.

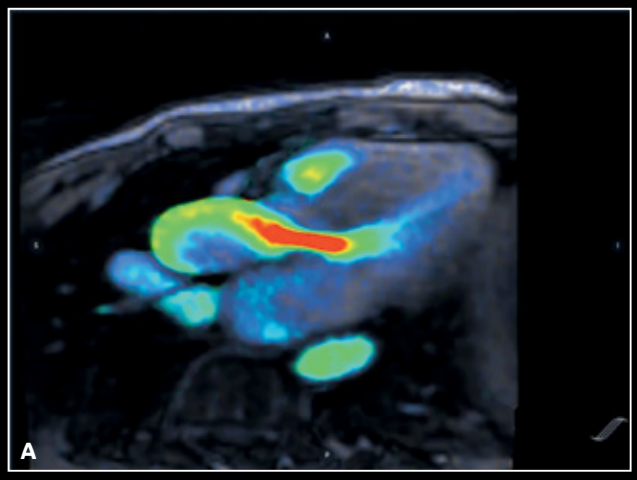
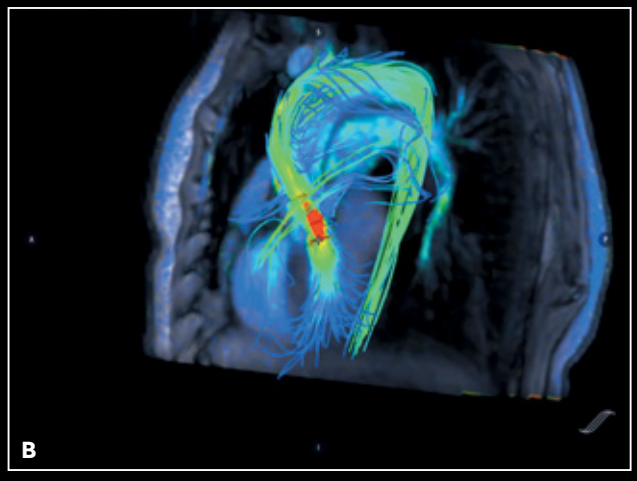
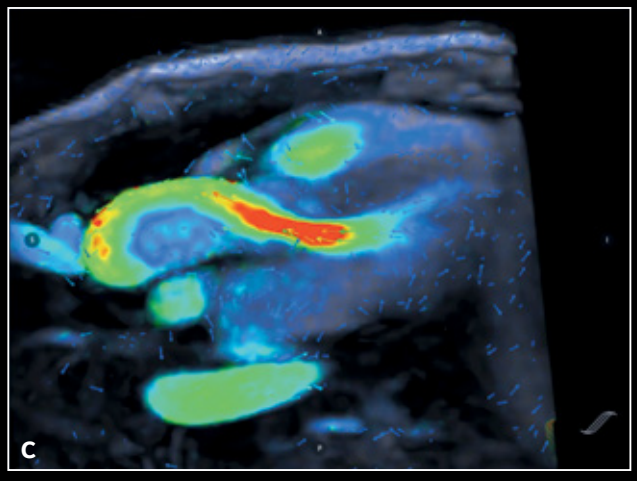


Figure 3. (A) Flow acceleration in the left ventricular outflow tract due to myocardial hypertrophy. (B, C) Eccentric jet flow in the tubular ascending aorta with turbulent flow. Diameter of the aorta: 31 mm.





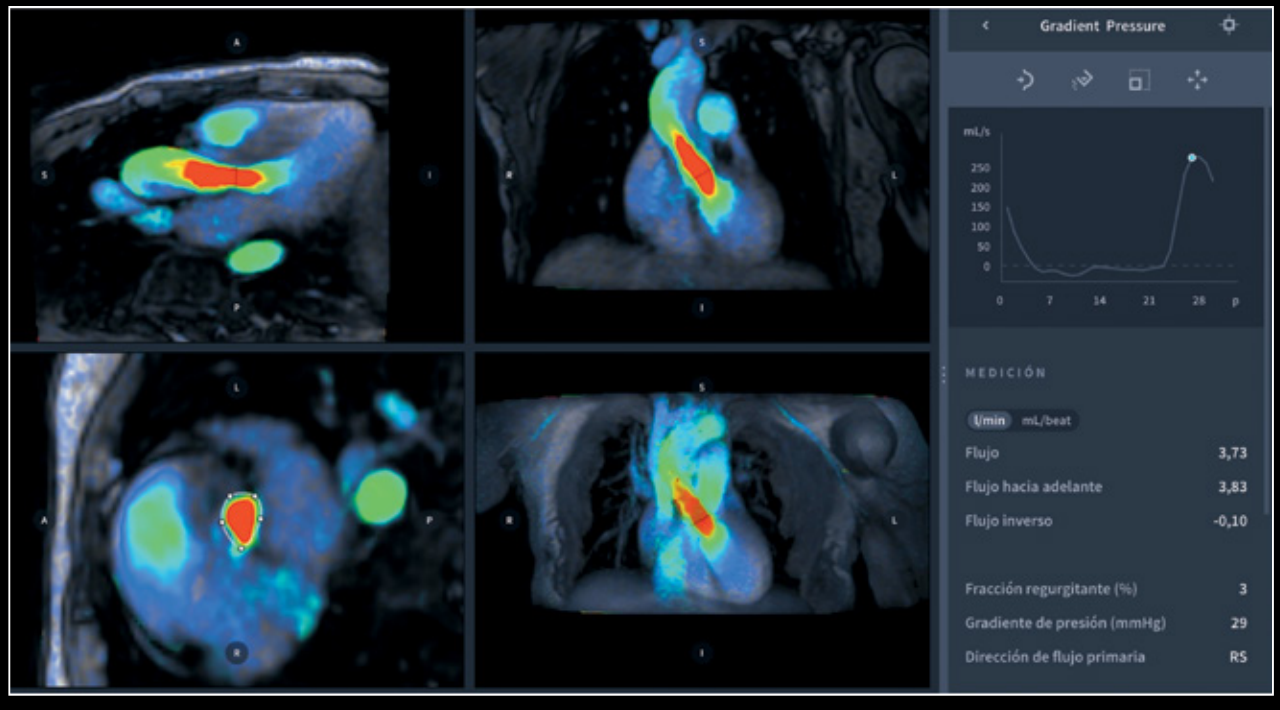
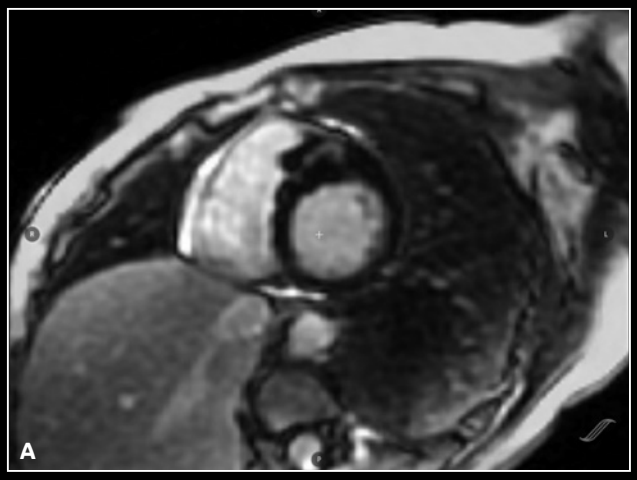


Figure 4. Gradient Pressure: 29 mmHg.



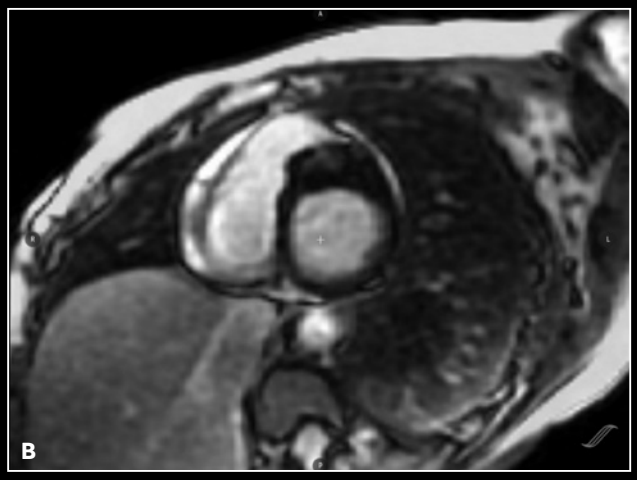
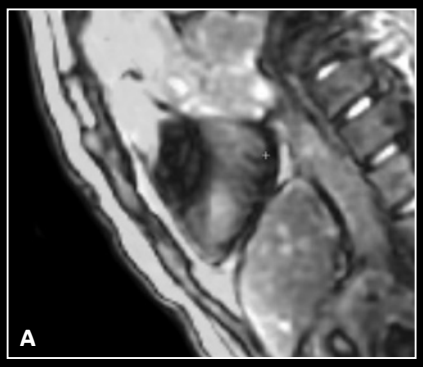
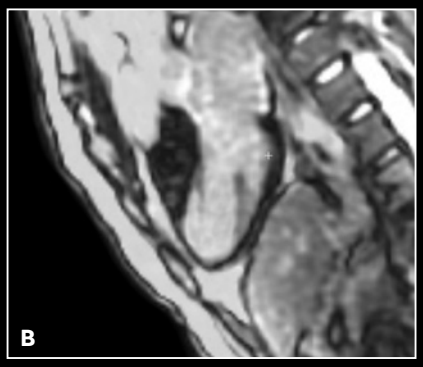


Figure 5. Short axis. Late enhancement (single shot).





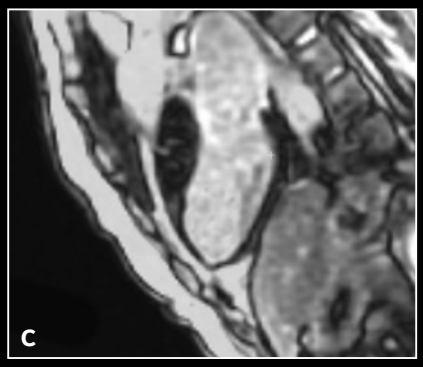


Figure 6. Long axis. Late enhancement (single shot).

Discussion

The main drawback of CMR is the long acquisition and interpretation times. Thus, a main objective is to reduce scanning and post-processing time to enhance the diagnostic quality of CMR and increase clinical productivity. Newer, fast sequences such as 3D Cine and late enhancement single shot significantly reduce scan time.

4D Flow provides comprehensive information on a patient's vascular and valvular flow with a reasonable acquisition time. This sequence has several advantages with respect to the 2D phased-contrast sequences:

- Flow volume measurements with 4D Flow have good internal consistency
- QP/QS is obtained in the same dataset (same cardiac cycle)
- Retrospective placement of analysis planes at any location
- Valve tracking may improve assessment of flow in the heart valves
- Free breathing
- Easy to prescribe

The post-processing capabilities of ViosWorks using deep learning algorithms delivers quantitative data and structured reporting capabilities and also reduces time and increases a radiologist's productivity.

Advanced visualization applications for quantitative MR imaging

by Heide Harris, RT(R)(MR), Global Product Marketing Director, MR Applications and Visualization, and Steve Lawson, RT(R)(MR), Global MR Clinical Marketing Manager

Quantitative imaging has been described as the next evolution in MR imaging, with the potential for improved diagnostic accuracy and workflow[1]. As medicine moves toward personalized/precision healthcare, it is expected that there will be an increased demand for quantitative imaging, both in MR and in other imaging modalities. Quantitative imaging helps the radiologist assess the patient's current condition and provides data for diagnosis, prognosis and therapy planning through biomarkers across a spectrum of disease states[2]. The Quantitative Imaging Biomarkers Alliance (QIBA) was formed by the RSNA to accelerate the development and adoption of hardware and software standards for accurate and reproducible quantitative imaging results[3].

Yet, many radiologists are faced with growing demands to read more studies per hour while juggling more data from these studies, including the desire to quantitate the data. Compounding this situation is that the radiologist may not have seamless access to the latest post-processing technology. MR administrators may hold off on upgrades and updates until the next capital budget plan, which can be years away. Or, the quantitative imaging and post-processing tools the radiologist needs are on a separate workstation, requiring an interruption in their reading workflow. The radiologist may move from reading station to workstations in other areas, suspend reading/reporting to track down images and data, create manual workflows or their own reporting templates, or report the case without extracting all the quantitative clinical information. This disruption leads to inefficiencies, reducing the quality of care and leading to longer report turnaround times.

Also consider that as technology advances so too does obsolescence. In a double-blinded survey of 142 radiologists, 49 percent were using visualization software older than three years[4]. Across a healthcare system, purchases made over time can result in different capabilities in different locations, making it more difficult to manage software versions and systems. Forty-eight percent of radiologists spend more than 15 minutes each day on non-value add tasks to report a case[4]. Nearly 2.5 GB of data is transferred per case, often multiple times, with 2.6 errors per day[4].

MR visualization applications

At GE Healthcare, advanced visualization starts with the Advantage Workstation (AW) Volume Viewer. It's the starting block for all post-processing application for all modalities with customized layouts, basic reformats, MIP and IVI features. The next level is Integrated Registration, a key application for MR-to-MR and multi-modality alignment and fusion, based on a rigid-motion algorithm.

Volume Viewer delivers a rich 3D image processing toolset to create different views and further streamline interpretation and reporting with visualization tools that require minimal clicks and user input. Specifically, tools such as AutoContour provide an automated, two-click measurement of a lesion based on the maximum dimension and volume. The AutoSelect segmentation tool helps to add or remove any continuous structures of

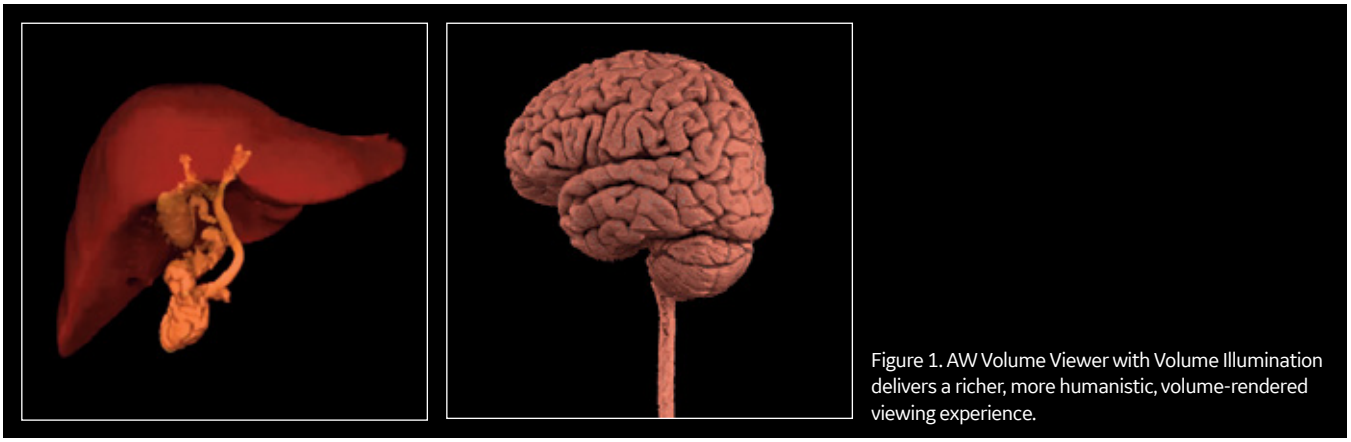


Figure 1. AW Volume Viewer with Volume Illumination delivers a richer, more humanistic, volume-rendered viewing experience.

interest by a simple point and click. Users can also access advanced segmentation tools like scalpel, threshold and subtraction, which are commonly used to finely tune the image data. The collection of measurements can be captured in the Summary Table that is accessible by date and exported and/or copied into a clipboard for easy communication via email or to embed in reports.

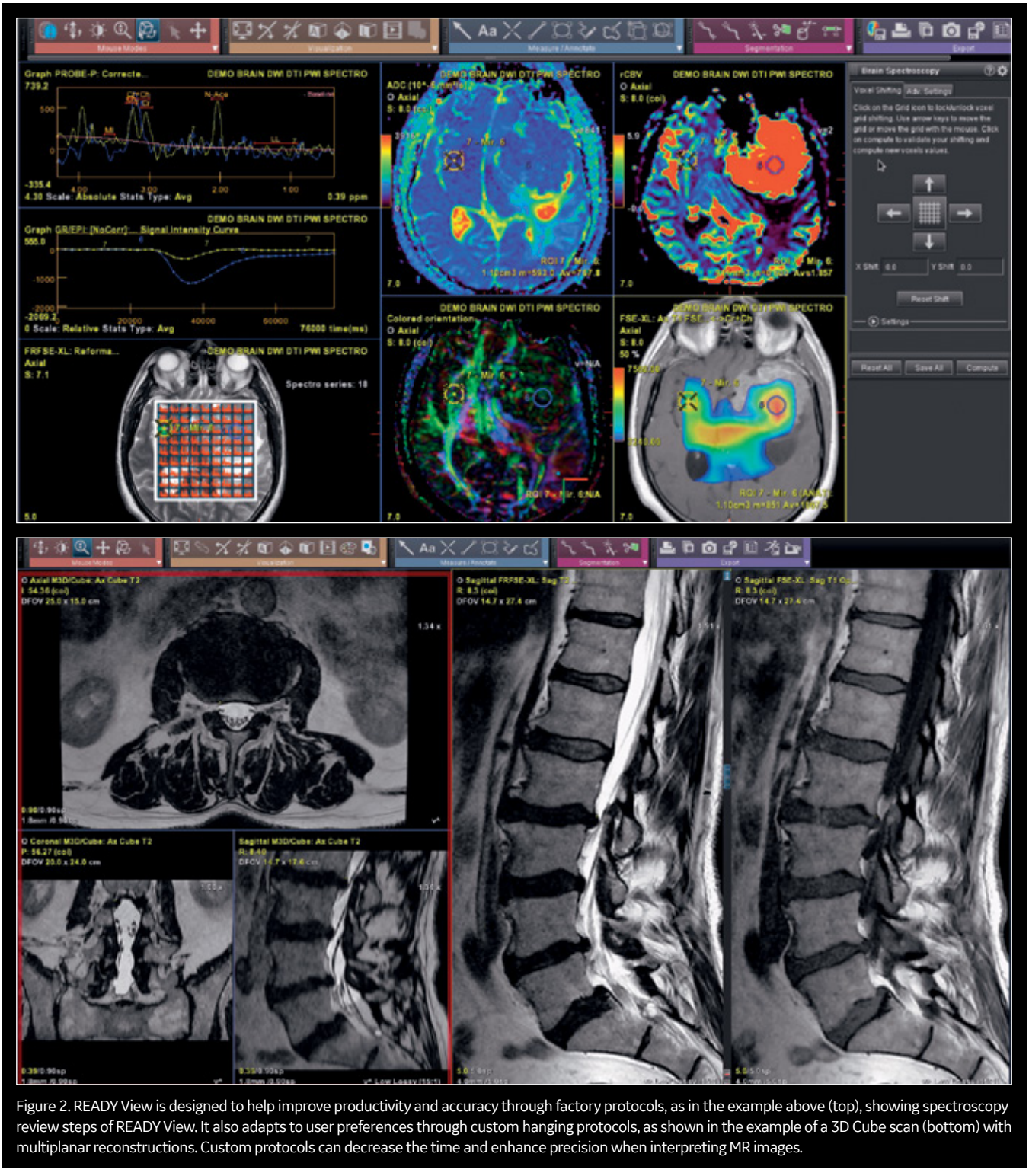


Figure 2. READY View is designed to help improve productivity and accuracy through factory protocols, as in the example above (top), showing spectroscopy review steps of READY View. It also adapts to user preferences through custom hanging protocols, as shown in the example of a 3D Cube scan (bottom) with multiplanar reconstructions. Custom protocols can decrease the time and enhance precision when interpreting MR images.

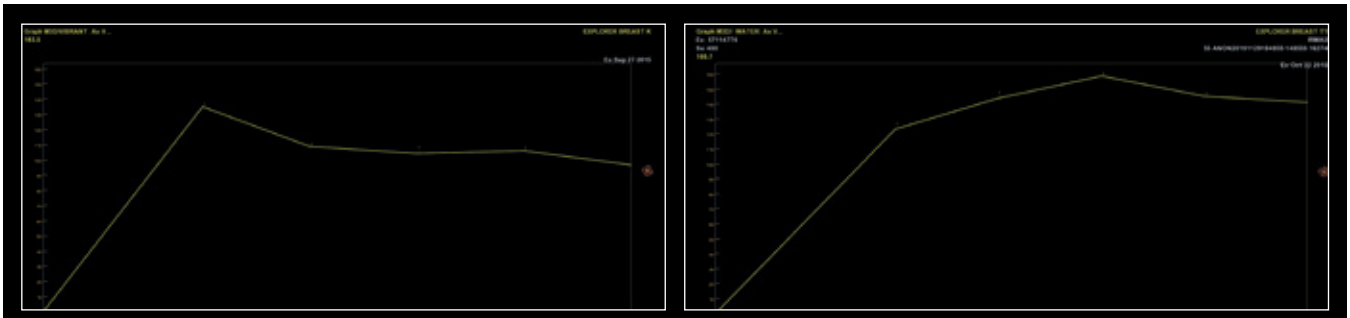


Figure 3. Time course curves provide information on lesion characteristics and treatment response.

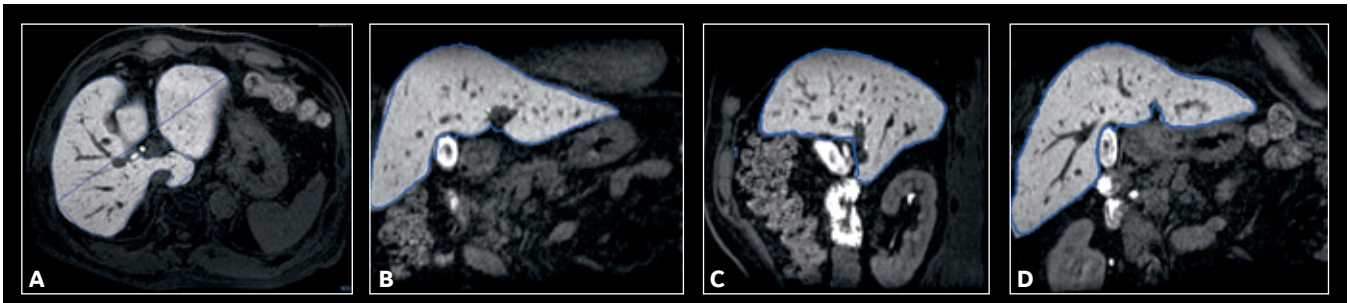


Figure 4. (A) Advanced measurement tools allow the radiologist to segment anatomy, in this case a liver, and then reformat into (B) oblique, (C) coronal and (D) sagittal views that can then be measured for a comprehensive evaluation.

Specific to MR is READY View, designed to help improve productivity and accuracy through factory or custom hanging protocols that can decrease the time and enhance precision when interpreting MR images. READY View offers ADC, DTI, T2 Map, R2*, single and CSI spectroscopy, fusion and multi-parametric review. A multi-parametric MR approach generates zones within a lesion that reflect heterogeneity and often display characteristic patterns. These attributes have proven to be useful in the diagnosis of tumors, monitoring tumor growth and guiding biopsies. Yet, quantifying the information from multi-parametric studies, which often include both a diffusion and perfusion scan, can be very challenging and time consuming. READY View streamlines multi-parametric analysis of MR data sets with multiple images for each scan location. The user experience driven framework offers a combination of protocols and tools that help make quantified analyses of multiple data sets quick and easy.

Integrated with READY View are BodyView and BrainView. BodyView is GE's primary application for streamlining the review of dynamic MR imaging of the body, including the liver, breast and prostate. It provides algorithms, tools and workflows for processing time series data acquired in the body. It also calculates parametric images from contrast enhanced images based on the temporal evolution of signal intensity before and after contrast. Time course curve shapes can be viewed to determine lesion characteristics and treatment response.

In the brain, spectroscopy, DWI, DTI, Time Course series and functional imaging techniques provide physiological information on metabolism and hemodynamics beyond conventional anatomic and structural imaging data. BrainView combines hemodynamics (BrainStat/ASL) and microstructure (FiberTrak) information for fast characterization of vascular-deficient or vascular-rich brain regions and white matter damage. It includes BrainSTAT AIF/GVF for brain (T2*) perfusion DSC imaging, including leakage indicator maps for more accuate AIF curves in tumor imaging, 3D ASL and FiberTrak (quantitative) in all orientations.

Body visualization

The demand for body imaging in MR continues to rise, particularly in the pelvis and abdomen, liver, prostate and breast. Many body MR procedures are for oncology patients and the gobal incidence of cancer continues to increase[5]. As the MR exams become more frequent – a 31 percent increase in the utilization of MR from 2007 to 2018[6] – and the exams become more complex, the use of advanced quantitative visualization applications becomes more important.

Along with the growing demand for prostate MR imaging, up 23 percent over the last seven years, so too has the need for more efficient tools grown. In fact, according to the 2019 IMV Outlook Report, "fast and focused prostate imaging with improved CAD analysis," was specifically called out as top of mind for customers performing prostate MR imaging[6]. Building off this growing demand and need, PROView provides easy and intuitive guided workflow and multi-parametric assessment of the prostate for reviewing, scoring and reporting. PROView integrates PI-RADS® v2.1

compliant reporting guidelines to help standardize the MR evaluation of prostate cancer and produces an exportable report for referring physicians. GE anticipates that PROView will utilize deep-learning-based Auto Segmentation[‡] that is designed for automated contouring and measurement of the prostate gland. When the information from Auto Segmentation is combined with a patient's PSA level, it may help determine the PSA density of the prostate, which is relative to its size, to provide consistent results that are critical in a radiologist's evaluations. PROView is integrated into the Volume Viewer framework and can be incorporated into customized protocols within READY View, for example to generate the ADC map series. Just as PI-RADS® standardizes prostate MR, BI-RADS® standardizes breast MR. CADstream® is an automated breast reporting, data visualization and segmentation solution that simplifies workflow for characterizing abnormalities accessing prior studies and planning intervention, such as surgery. Extensive visualization options for breast review assists radiologists by accelerating and simplifying the interpretation of large studies like digital breast tomosynthesis. It has a BI-RADS® centric user interface and deep analytic tools including registration and kinetics. CADstream® can be launched from PACS for multiple users and decreased post-processing time.

Figure 5. PROView provides easy and intuitive guided workflow and multi-parametric assessment of the prostate for reviewing, scoring and reporting. The deep-learning-based Auto Segmentation[‡] is designed for automated contouring and measurement of the prostate gland. The PROView report can be exported into HTML format for easy editing and/or intergrated into dictation software.

[‡]510(k) pending at FDA. Not available for sale.

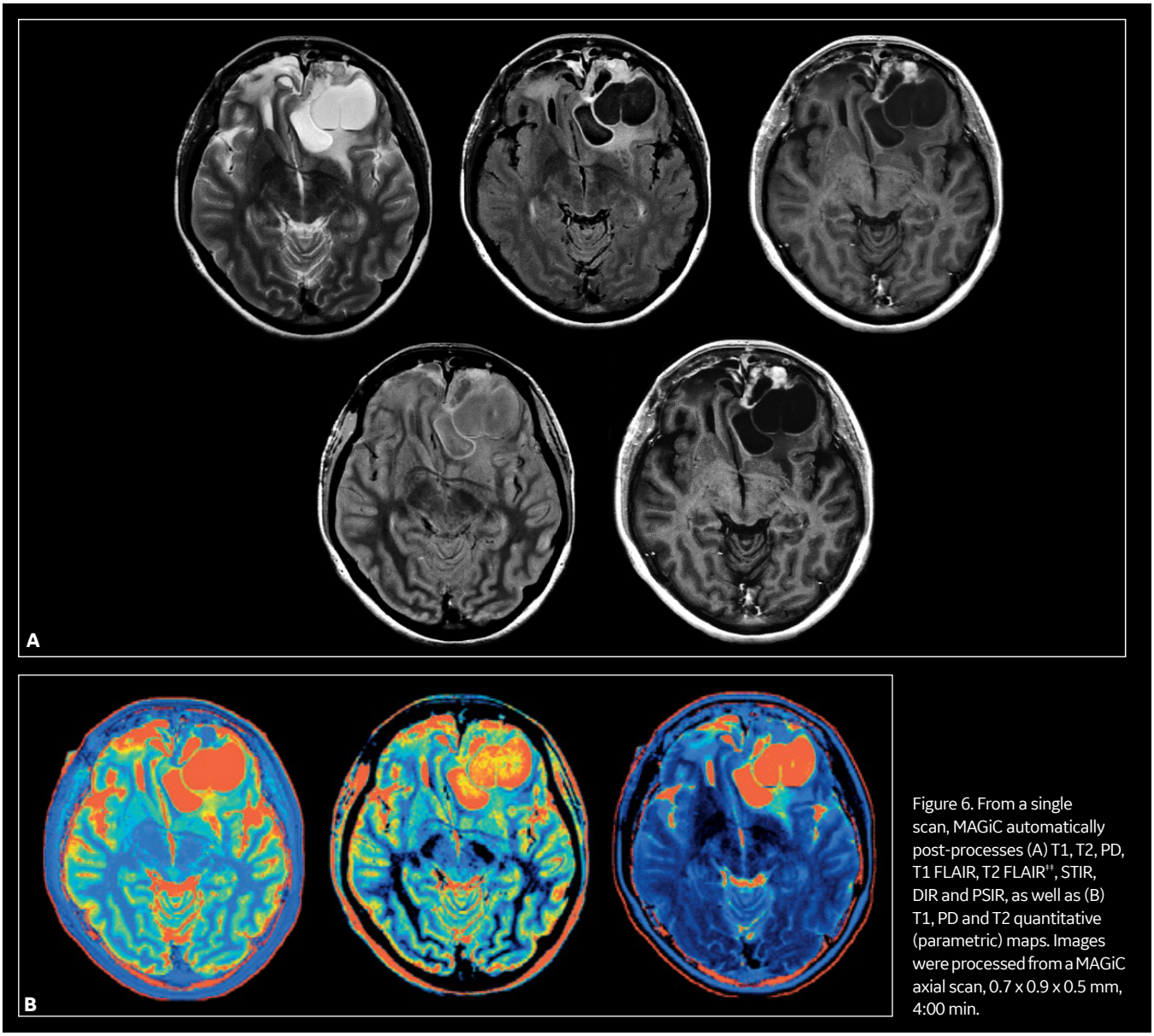


Figure 6. From a single scan, MAGiC automatically post-processes (A) T1, T2, PD, T1 FLAIR, T2 FLAIR[††], STIR, DIR and PSIR, as well as (B) T1, PD and T2 quantitative (parametric) maps. Images were processed from a MAGiC axial scan, 0.7 x 0.9 x 0.5 mm, 4:00 min.

Liver disease, including NAFLD and NASH, is also growing worldwide with one in five young adults and nearly one in 10 children having fatty liver disease[7,8]. MyLiver Check-up pairs MR Touch and IDEAL IQ with the MRE+ reporting from Resoundant for a comprehensive, non-invasive approach to assessing early liver disease in less than 10 minutes. MRE+ provides automatic ROI placement and calculation, driving consistent results for liver stiffness, fat and iron calculation. MyLiver Check-up provides a rapid, quantitative evaluation of the whole liver that delivers consistent and reproducible results as opposed to selective liver biopsy.

For more information on MyLiver Check-up, visit https://tinyurl.com/yd6zn77j.

Neuro visualization

Neuro imaging has been a staple for MR, with more than half of all exams focused on the spine (26 percent) and the brain (30 percent). Continued growth is expected as MR is being tapped to assess mental health, neurodegenerative, stroke and traumatic brain injury patients. In many cases, neuro MR imaging requires consistency and repeatability across scans to evaluate the progression of disease and response to treatment. For many neurological diseases, multi-parametric techniques and quantitative analysis of the MR imaging data are crucial components guiding patient care decisions.

In one single scan, MAGiC combines the power of the scanning acquisition with powerful processing to automatically deliver T1, T2, PD, T1 FLAIR, T2 FLAIR[††], STIR, DIR and PSIR, as well as

[††]It is recommended to acquire conventional T2 FLAIR images in addition to MAGiC.

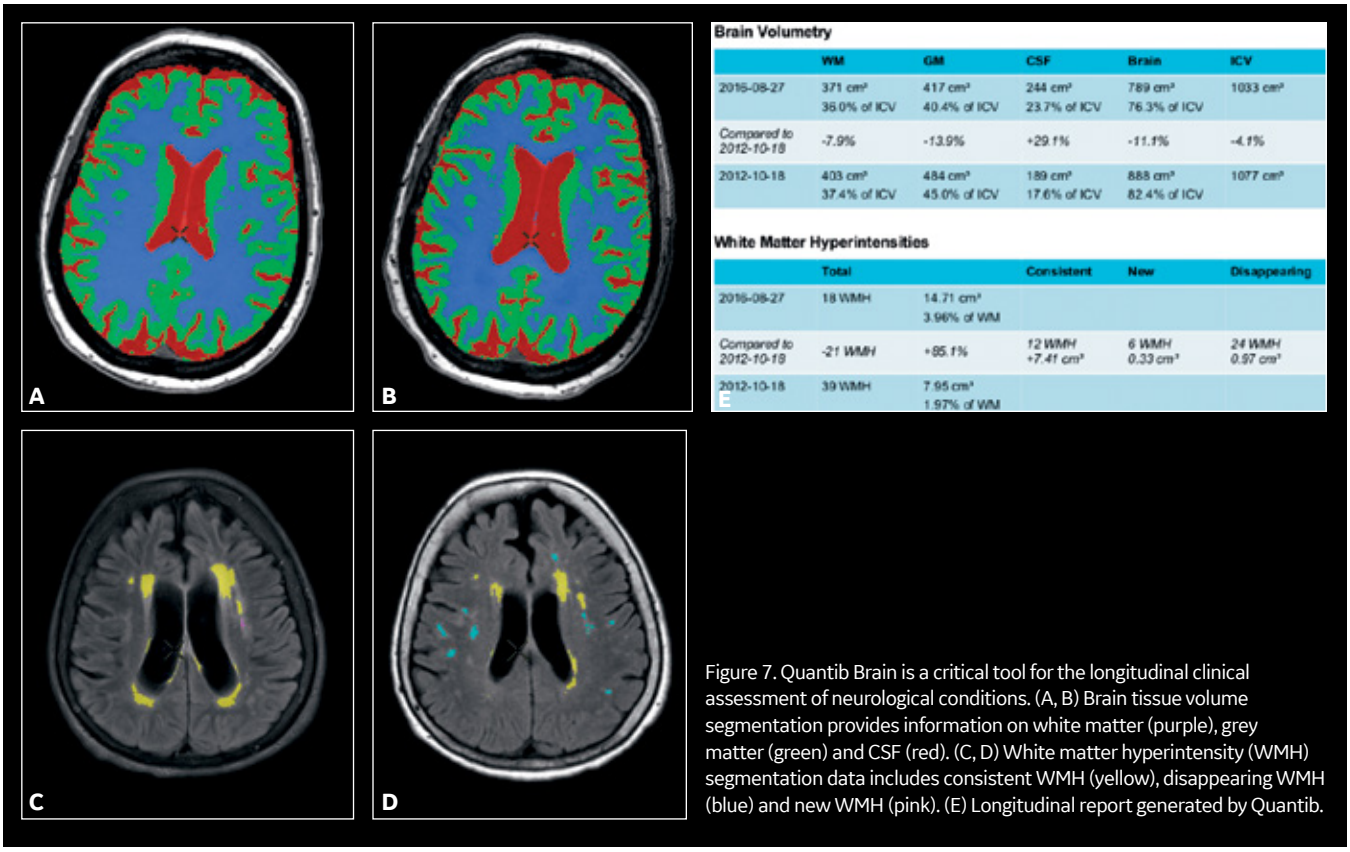


Figure 7. Quantib Brain is a critical tool for the longitudinal clinical assessment of neurological conditions. (A, B) Brain tissue volume segmentation provides information on white matter (purple), grey matter (green) and CSF (red). (C, D) White matter hyperintensity (WMH) segmentation data includes consistent WMH (yellow), disappearing WMH (blue) and new WMH (pink). (E) Longitudinal report generated by Quantib.

parametric maps, in approximately 5 minutes of scan time. After the scan, MAGiC generates images of any TR, TE and TI with the flexibility to change image contrasts even after the exam has ended on the MR console or on AW.

Quantib Brain, in conjunction with Quantib B.V., provides a seamless integration of brain volume quantification on the AW and AW Server and delivers a comprehensive, exportable report. Quantib's deep-learning-based segmentation of the brain for auto labeling, visualization and volumetric quantification of structures, as well as detection of white matter hyperintensities, is based on 3D T1 and T2 FLAIR (3D and 2D) acquisitions. Quantib Brain is a critical tool for the longitudinal clinical assessment of neurological conditions such as age associated neurodegenerative conditions, Alzheimer's disease or multiple sclerosis.

NeuroQuant® from CorTechs Labs is a cloud-based solution that automatically segments, measures and quantifies volumes of brain structures and compares the volumes to a normative database adjusted for age, sex and intracranial volume. It assists with identifying and assessing neurodegeneration in its earliest stages to aid in treatment and lifestyle planning for patients.

For a one-stop-shop fMRI solution from paradigm creation through acquisition to visualization and exporting/reporting, BrainWave is available on the MR scanner or AW. It delivers real time monitoring of data to ensure quality of the acquisition before a patient leaves and fully automates processing – when the exam is done, the images are ready.

Oncology visualization

In 2018, there were an estimated 17 million new cancer cases worldwide and that number is expected to increase to 27.5 million by 2040[5]. MR imaging, including whole-body MR, is increasingly being used to detect and evaluate cancer in the body and the brain due to its high soft-tissue contrast and excellent spatial resolution. In addition to anatomical imaging, MR applications include advanced functional assessment techniques. In oncology, some of these new techniques can provide beneficial information on angiogenesis inhibitors in addition to the tumor size criteria (determined by the World Health Organization) and Response Evaluation Criteria in Solid Tumors (RECIST). Because of its capability to noninvasively measure angiogenesis, dynamic contrast-enhanced MR (DCE-MR) is becoming a standard method for directly assessing the vascular properties in lesions.

GenIQ delivers quantified DCE-MR image analysis and permeability maps to assess vascular properties in lesions. It helps to assess tissue vascular properties in lesions – quantitative pharmacokinetic (PK) modeling – with a contrast-perfusion (dynamic contrast-enhanced) approach to help assess angiogenesis. GenIQ uses rapid 3D T1 perfusion (LAVA, VIBRANT or DISCO) data to provide a quantitative, non-invasive approach to help grade and

Figure 8. GenIQ uses rapid 3D T1 perfusion (LAVA, VIBRANT or DISCO) data to provide a quantitative, non-invasive approach to help grade and diagnose tumors.

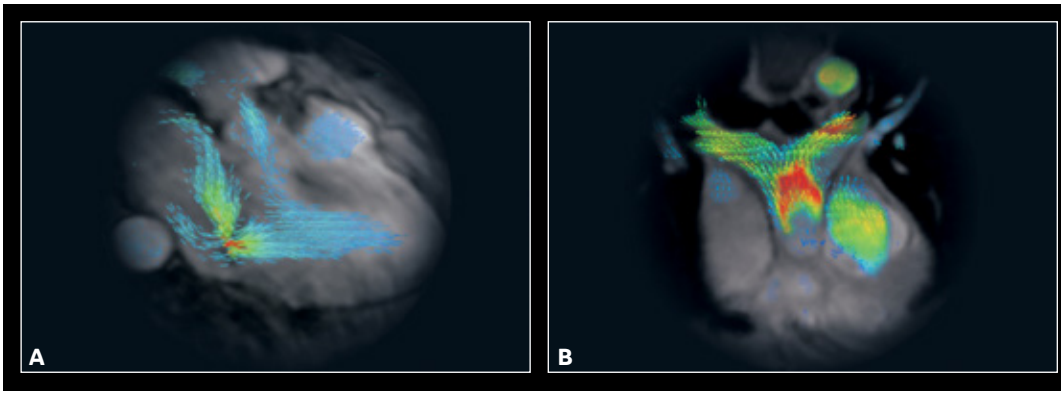


Figure 9. ViosWorks 4D Flow provides flow velocity and direction of flow information for (A) valvular and (B) congenital heart disease.

diagnose tumors. (kTrans is the key quantitative data provided.)

OncoQuant™ is the multi-modality, multi-time point oncology diagnosis, follow-up, reporting and management tool. Due to the expanding breadth of data associated with today's oncology studies, reviewing these exams can be time consuming and labor intensive. AW's OncoQuant application is designed to help organize and display oncology data to facilitate quick review. Both routine comparisons and advanced clinical evaluations may benefit from the OncoQuant workflow to navigate through findings and interact with results.

Cardiovascular visualization

Cardiac MR (CMR) is a valuable tool for assessing a vast array of anatomical and functional cardiac abnormalities, including myocardial edema, myocardial siderosis, myocardial perfusion, diffuse myocardial fibrosis, congenital heart disease, heart failure, cardiac masses, pericardial disease and coronary artery disease[9]. Continued advances in visualization and image reconstruction techniques may further increase the clinical utility of CMR with 3D volumetric imaging and accelerate image acquisition and quantitative analysis[9].

ViosWorks leverages the imaging analytic power of the Arterys™ cloud-based platform to precisely visualize and quantify cardiac flow. It's platform integrates seamlessly into clinical practice to provide simple and quick cardiac MR imaging data that is uploaded to the cloud for processing, facilitating immediate reconstruction of a 2 mm^3 scan and enabling clinical review before the patient gets off the table. It improves patient comfort through a free-breathing 4D Flow scan, simplifies patient set-up with one slab to cover the whole heart and provides precise quantitative measurements that can be accessible from any computer. ViosWorks 4D Flow delivers functional cine information along with flow velocity and direction of flow information.

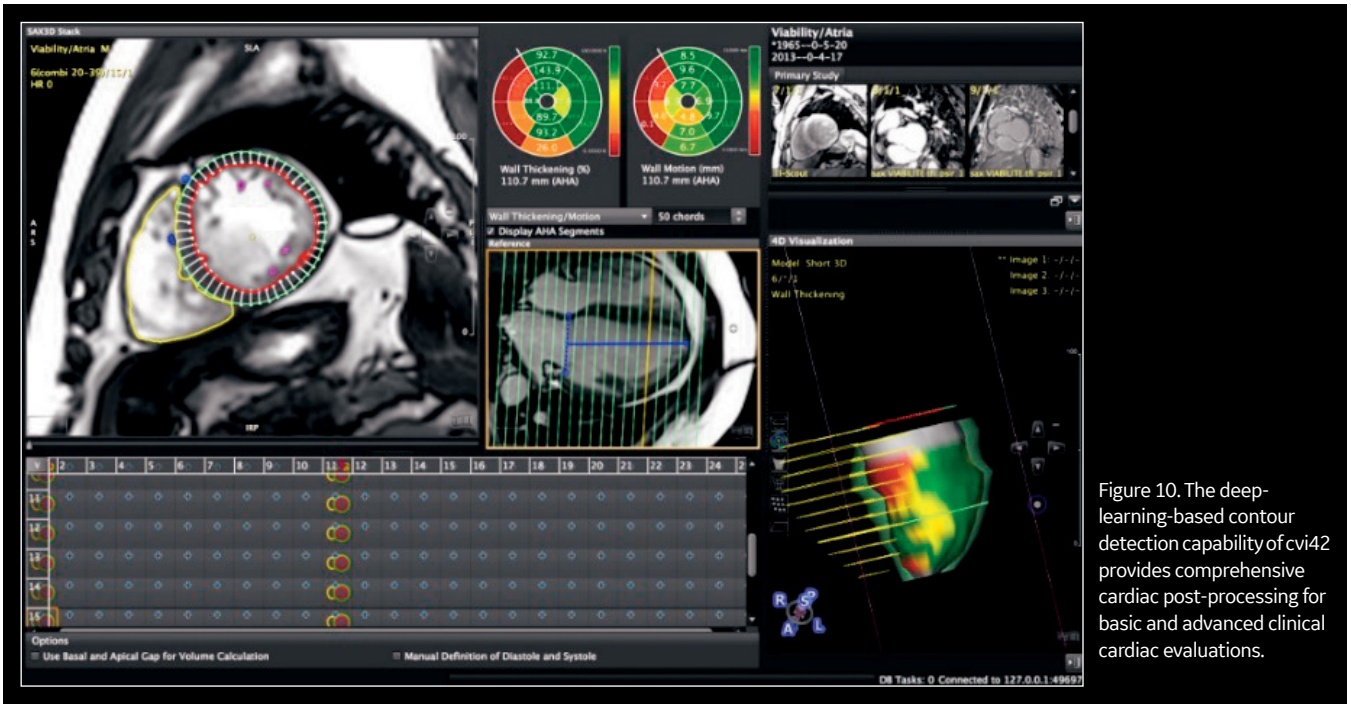


Figure 10. The deep-learning-based contour detection capability of cvi42 provides comprehensive cardiac post-processing for basic and advanced clinical cardiac evaluations.

cvi42 from Circle Cardiovascular Imaging uses artificial intelligence trained algorithms to provide single click results, from basic cardiac assessments to advanced clinical cardiac evaluations. In just seconds, the deep-learning-based contour detection capability of cvi42 provides comprehensive cardiac post-processing on the AW, AW Server or a stand-alone system that saves time with improved reading and reporting efficiency and optimized module performance.

suiteHeart® enables function and flow analyses, time course, delayed enhancement and more; MR VesselIQ Xpress provides 3D visualization, tracks vessel centerline, quantifies abnormalities and enables assessment of vessel tortuosity, longitude and cross section and profile.

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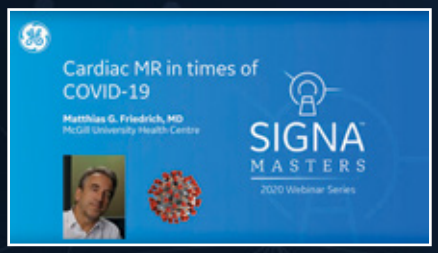


Cardiac MR in times of COVID-19

Matthias G. Friedrich, MD
McGill University Health Centre

Impact of Deep-Learning Reconstruction on Myocardial Delayed Enhancement Imaging

Marco Guglielmo, MD FEACVI, FSCC
Centro Cardiologico Monzino, IRCCS

SIGNA™ Masters 2020 Cardiac Summit, 3-Part Series:

1. State of Cardiac MRI

2. Quantitative Myocardial Perfusion

3. Rapid & Deep-Learning Power Workflows in Cardiac MR Imaging

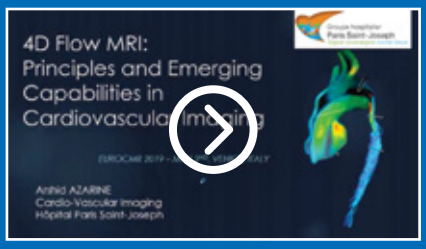
Various Speakers

Recommended viewing

4D Flow MRI: A revolution for Congenital Heart Disease

Francesca Raimoni, MD
Hôpital Necker-Enfants Malade,
Paris, France

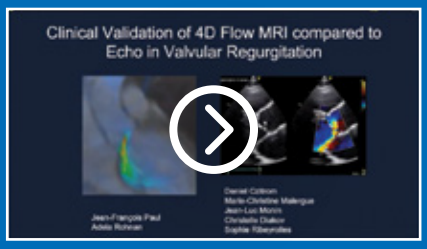
https://www.youtube.com/watch?v=wdAB0SzO-IM&feature=youtu.be



4D Flow: Technical principles and emerging capabilities in CMR analysis

Arshid Azarine, MD
Hôpital Paris Saint-Joseph,
Paris, France

https://youtu.be/wdAB0SzO-IM



Clinical validation of 4D Flow MRI for Cardiac Valvular Disease

Jean-Francois Paul, MD
Institut Mutualiste Montsouris (IMM)
Paris, France

https://youtu.be/GIMZKyVhSCw

Short cardiac MR protocols: Where they work

Matthias Friedrich, MD
McGill University, Montreal, Canada

https://youtu.be/vB1-j-oI53A

Getting consistent and quantifiable results in cardiac imaging

Alexander Hirsch, MD, PhD
Erasmus Medical Center,
Rotterdam, NE

https://youtu.be/dQ3-sU-kPv0

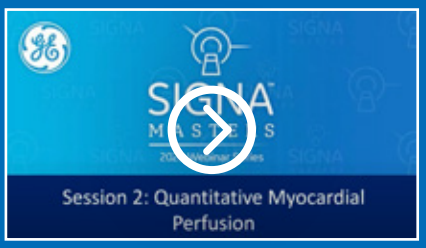
Read more about AIR™ Recon DL and MDE:

https://doi.org/10.1007/s00330-020-07461-w

State of Cardiac MRI

Matthias Friedrich, MD,
Jonathan Weinsaft, MD

https://www.youtube.com/watch?v=XuBAMCjN4QM



Quantitative Myocardial Perfusion

Amet Patel, MD, Mitchel Benovoy, MD,
Haonan Wang, MD

https://www.youtube.com/watch?v=zNQ7Mivgkdg

Rapid & Deep-Learning Power Workflows in Cardiac MR Imaging

Matthias G. Friedrich, MD,
Shreyas Vasanawala, MD, PhD,
Reza Forghani, MD, Elizabeth Hillier, MD

https://www.youtube.com/watch?v=Qax9sXCwmmw

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