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TAKING MRI TO HEART

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INTRODUCTION

Magnetic resonance imaging (MRI) is one of the fastest evolving modalities with respect to advanced medical imaging technology. One of the major advantages of using MRI is the fact that it is a noninvasive (or minimally invasive) procedure that produces high-end images for diagnostic purposes. However, early MRI researchers struggled to overcome the artifacts that were associated with motion. Because of this, heart imaging was suboptimum. That is, the very motion associated with the beating of the heart and the flow of the blood through the coronary arteries hindered obtaining clearly readable images.

Today, with the refinement of software that addresses the special considerations of heart imaging, MRI has moved into a position of prominence regarding diagnosing cardiac problems. This position is quite significant when minimally invasive MRI procedures are compared to the very invasive tests performed in cardiac catheterization laboratories. To obtain the same information that cardiac MRI scanning produces, patients in the cardiac catheterization laboratories are subjected to femoral artery punctures, followed by catheterization of the coronary arteries through the puncture site. The risks inherent in these procedures include:

- Dislodging of plaque from artery walls
- Tearing of arterial lumens, leading to possible dissection
- Irritation of the heart muscle, leading to possible arrhythmias
- Possible complications from the femoral puncture site
- Possible allergy to the iodine-based contrast agent used (some patients may even develop life-threatening anaphylactic reactions)
- Use of ionizing radiation to produce images

In comparison, MRI uses a noniodine-based contrast agent, which is delivered through an intravenous (IV) system to produce cardiac images. The patient is given a bolus of the contrast agent, and the images are collected as the contrast washes through the heart and coronary vessels. Once the scan is finished, the patient does not face the postoperative challenges that have been inherent in traditional cardiac imaging. MRI truly is the medium of choice because this cutting edge technology is less invasive, thus causing less discomfort to patients.

To provide technologists with a working knowledge of cardiac MRI issues, the following four areas will be addressed: physics, special techniques, contrast considerations, and examples of pathology that can be detected through the use of cardiac imaging in the MRI suite.

PHYSICS

When patients are brought into the MRI suite, a phenomenon of physics occurs that cannot be felt by the patient or technologist. Because of the increased magnetic field around the imager, the hydrogen nuclei (or protons) in the human body align with the external magnetic field. This occurs because these atoms are *dipoles*. A magnetic dipole is a concept used in physics to describe the emanation of local magnetic fields from individual molecular, atomic, and subatomic particles (ie, ions, protons, electrons).

Nearly 80% of the atoms in the human body are hydrogen, and once alignment occurs the patient is said to be at "net magnetization." The patient, at this point, has actually been transformed into a magnet, with a north and south pole.[1]

One of the more fascinating points about the physics of MRI is the fact that not all of the proton dipoles align with the magnetic field produced in the MRI suite. In actuality, only one out of every million truly align to produce the net magnetization. Still, with this seemingly small number of protons participating in the process, a strong MRI signal can be produced that can be translated into quality images.

Net magnetization alone is not enough to produce a magnetic resonance image. Once net magnetization is achieved, the technologist will send a radiofrequency pulse through the patient. The protons will absorb the pulse and will then be knocked out of alignment with the external magnetic field. Once the pulse is discontinued, the protons will realign themselves with the external magnetic field that is always present in the scanning room.

The length of time needed for each proton to relax back to equilibrium is recorded and translated by the software to produce the images that are seen as an end result.[1]

As previously mentioned, motion is an enemy of quality MRI scanning results. If motion is present, such as *respiration* or *heart contractions,* it becomes very difficult to accurately measure the length of time needed for the protons to relax and realign with the external magnetic field. Grainy, blurry images will result. This is especially important to consider when imaging the heart because this organ is constantly in motion.

To overcome the challenge of motion in the cardiac muscle, some ingenious methods have been developed to produce quality images. Respiratory motion is addressed by instructing the patient to hold his or her breath for a period of time (ie, approximately 20 sec) while the acquisition is occurring. Even so, the heart is still in motion; this situation must be addressed separately to avoid collecting signal from both the systole and diastole phases. Electrocardiogram leads are used to provide information about the electrical activity of the heart. The rhythm is gated, which allows the technologist to acquire information from the same point in the cardiac cycle to reconstruct the images. The technologist also determines the thickness of the slice (location) that is being surveyed. An individual slice can be re-sampled over and over again at the same point in the sinus rhythm to obtain more information. More than one slice is surveyed, and the end result is a series of high-quality images that can provide information about the anatomy and pathology of the heart muscle.[2]

The radiofrequency pulse sequences associated with the early cardiac MRI scans are called *spin-echo* and *gradient-echo* techniques. Simplified, these are two different techniques of sending out the radiofrequency so that the protons are manipulated differently. The resulting signal that is collected produces images that are characteristic to the particular pulse sequence.

In the spin-echo technique, two different radiofrequencies are used to produce the final magnetic resonance signal. In contrast, a single radiofrequency pulse is used in the gradient-echo technique to excite the protons so they will resonate back the MR signal upon relaxation. One particularly useful characteristic of the spin-echo technique is that it generates an absence of signal from flowing blood. This absence is termed a *flow void,* which is very helpful in delineating vascular walls that are often involved in cardiac disease processes.[3]

SPECIAL TECHNIQUES

Based on spin-echo and gradient-echo pulse sequencing for cardiac imaging, MRI software has been refined that allows for optimum visualization of the heart and coronary arteries. Fast gradient-echo sequences have been developed that allow for *cine* techniques to be obtained using MRI. Cine techniques are usually repeated at 20- to 30-msec intervals to image either a single slice or multiple slices at a large number of consecutive points throughout the cardiac cycle.[3] Cine technique can be applied to several slices in the heart, and then the resulting images are interleaved to produce the cine loop. Without using invasive cardiac catheterization and radiation, a cine can be obtained that produces the same useful diagnostic information. *Real-time imaging* is being tested at sites with advanced software.

Cine MRI is also used when technologists use myocardial tissue tagging techniques for visualization. Magnetically tagging tissue is accomplished through a complex series of manipulations with respect to the radiofrequency pulses and the collection of the resonating signal. The heart is labeled with a dark grid, and a three-dimensional analysis of cardiac rotation, strain, displacement, and deformation of different myocardial layers during the cardiac cycle is performed.[4] This technique can be performed during systole or diastole, with images being produced as frequently as every 20 msec.[5] Myocardial tissue tagging is very useful in assessing wall motion and regional wall thickening.

Phase-velocity mapping is another special MRI technique that has been used to gather information about the heart and cardiac vessels. Simply put, phase-velocity mapping can encode the velocity of the blood flow in a specific direction, which can then be mapped to determine flow or pressure gradient measurements.[6] The physics of this technique relies on producing pixel intensities that are equivalent to the velocity of the blood flow.

Fast cardiac imaging is the goal for advancing software. General Electric has introduced fast methods called *snapshot* (or *turbo FLASH*) techniques that allow images of the heart to be acquired in 200 to 500 msec. This fast imaging is very useful for looking at cardiac perfusion and tracking contrast bolus injections.[7] By capturing the images rapidly, only one bolus of contrast is needed to perform the entire study.

CONTRAST CONSIDERATIONS

Contrast agents have been shown to be very beneficial in cardiac MRI studies. When the contrast is used in collaboration with the appropriate scanning techniques, optimum visualization of the heart and coronary vessels can be achieved. Flow of the blood through the arteries, as well as through the chambers of the heart, can be visualized. Valvular and coronary wall motion can also be imaged and examined.

Contrast agents in MRI studies have long been employed to image tumors and disease processes throughout the body. With the advent of magnetic resonance angiography (MRA) and magnetic resonance venography (MRV), the use of contrast agents has taken on a new challenge. These agents are used to actually show the flow of the blood through the arterial and venous systems of the entire body. An advantage that MRA and MRV have over traditional methods that introduce iodine-based contrast agents through catheters into the region of interest is that both arterial and venous flows can be imaged with a single bolus of noniodine-based contrast. To obtain optimum visualization in the traditional special-procedures catheterization laboratory, more than one injection of contrast agent would be needed to visualize both arterial and venous systems.

For purposes of cardiac imaging, the arterial system is generally the major system of interest. Even so, traditional cardiac catheterization techniques require that several injections of iodine-based contrast be introduced to visualize the entire network of arteries. This is generally achieved through individually selecting each coronary artery with a coronary catheter and then hand-injecting contrast agent into the artery while radiographic imaging is performed. Clearly, it is advantageous to the patient if cardiac imaging can be performed by the MRI scanner, for which only noniodine-based contrast is introduced through a minimally invasive IV setup.

One of the most commonly used contrast agents in the MRI suite is *gadolinium*. Imaging during breath holding while the contrast agent makes its first pass is a common procedure for MRI cardiac imaging.[8] The contrast agent is administered through an intravenous mode of delivery, which eliminates the complications associated with traditional heart catheterization. The contrast agent is normally bolused into the patient via a pressure injection, and the images are acquired rapidly as the contrast agent moves through the heart and coronary arteries.

Although it is possible to obtain very detailed images using MRI and contrast agents to visualize the heart, the case has been made that MRI cardiac imaging is not yet ready to completely replace the testing that occurs in the cardiac catheterization laboratories. One of the challenges is that the evolution of the processing techniques, contrast agents, and other technical considerations such as gating and breath-holding techniques is not equal.[8] Once each of these individual factors has evolved to its highest level, it is quite feasible that cardiac angiography will be moved from the catheterization laboratory to the MRI suite altogether.

EXAMPLES OF PATHOLOGY

One of the major reasons cardiac imaging is indicated is to assess the heart and coronary arteries after a *myocardial infarction,* commonly referred to as a heart attack. Each of the major coronary arteries—the right and the left (the latter which bifurcates into the left anterior descending artery and the circumflex artery)—supply a different part of the heart muscle with oxygenated blood. When a myocardial infarction occurs, blood flow is interrupted in one or several of the coronary arteries, resulting in damage to the part of the heart that the vessel feeds. Patients are usually cognizant that something is wrong because most experience pain when the heart has a loss of blood flow. If the flow is not restored in a timely manner, the part of the heart muscle associated with the affected artery will ultimately die.

If part of the myocardial tissue does indeed die due to a lack of oxygenated blood, it will not contract consistently with the rest of the beating heart. That part of the heart muscle is then said to be *nonviable* and will simply move with the motion of the rest of the heart. This motion resembles a balloon that has been over-inflated and then the air is released.

Myocardial viability can be successfully imaged with the use of contrast-enhanced MRI techniques.[9]

Breath-hold techniques, as mentioned previously, are very useful in evaluating tumor processes associated with the heart. Tumor activity can be visualized with MRI because of the difference in molecular composition of the diseased tissue. The patient's normal cardiac tissue will resonate differently than the diseased tissue associated with a tumor; the image that is reconstructed will demonstrate not only the location of the tumor but the composition of the tumor as well.

MRI techniques are also being used to diagnose *valvular heart disease*. Diseases of the valves include stenosis and morphology.[10] The flow of the blood across stenotic valves will not be normal, and the turbulence associated with the stenosis can be visualized and assessed using contrast-enhanced MRA. Not only are flow abnormalities diagnosable, but the velocity of the blood flow can also be measured to further assess the disease process. Regurgitation of blood flow can also be documented quite adequately.

Cardiomyopathy is a term used to denote many abnormalities associated with the heart muscle. By definition, the term denotes *heart muscle pathology*. When a patient presents with symptoms of cardiomyopathy (eg, decreased cardiac output), MRI can be instrumental in demonstrating the extent of damage to the heart muscle. Often, the cause of cardiomyopathy is unknown, and careful monitoring of patients stricken with this disease is critical for proper management. Breath-hold cardiac MRI techniques can be used to demonstrate thickening of the walls of the myocardium, as well as impaired diastolic and systolic ventricular function.[10]

Congenital heart disease is also very responsive to breath-hold MRI techniques. Congenital defects in very small children or infants can be visualized using non-breath-hold techniques, because it is difficult or even impossible to instruct these young patients about suspending respirations. With either technique, MRI can be used to diagnose coarctation of the aorta, lesions in the heart itself, and *congestive heart failure*.[10]

Anatomy that has been altered due to surgery is also a candidate for cardiac MRI. The changes associated with surgical repairs and reconstructions, as well as shunts, will often make the heart difficult to visualize using other methods of imaging. Again, MRI offers a clear, diagnosable alternative in this scenario.

CONCLUSION

Can MRI do it all with respect to cardiac imaging? The answer is an overwhelming, *"Almost!"* The progress in this area is astounding. Techniques are constantly being adapted to meet the challenges associated with imaging the heart. The software that has been developed is so sensitive that, in some cases, it is being "dumbed down" to obtain optimum images. Nearly every type of cardiac pathology is a candidate for MRI. Clearly, it is the imaging modality of choice when compared to others and their related complications. By working together, pharmaceutical companies, hardware and software developers, doctors, and technologists can take MRI to the next level, where it will be the first line of defense in diagnosing heart disease.

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SUGGESTED READING

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TAKING MRI TO HEART POST TEST

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1. **MRI uses what type of method to image the heart?**
   a. Noninvasive
   b. Very invasive
   c. Minimally invasive
   d. A and C
2. **One of the problems that faces cardiac MRI imaging is**
   a. high radiation exposure for the patient.
   b. anaphylactic shock from contrast agent reactions.
   c. motion.
   d. complications from hematomas.
3. **The femoral artery is punctured**
   a. when an MRA is performed.
   b. when a cardiac catheterization is performed.
   c. when a CT examination is performed.
   d. when a nuclear cardiology examination is performed.
4. **One of the risks inherent to traditional heart catheterization is**
   a. dislodging plaque from arterial walls.
   b. arrhythmias.
   c. dissection of the coronary arteries.
   d. all of the above.
5. **MRI uses what type of contrast agent?**
   a. Noniodine-based
   b. Iodine-based
   c. Saline and iodine
   d. Iodine and lidocaine
6. **A disadvantage to examinations that use iodine-based contrast agent is**
   a. anaphylactic reactions can occur and may be life-threatening.
   b. the high cost of the contrast agent.
   c. that iodine interferes with the magnetic field.
   d. any medications the patient may be taking must be discontinued before contrast agent administration.
7. **Nearly 80% of the atoms in the human body are composed of what?**
   a. Calcium
   b. Hydrogen
   c. Oxygen
   d. Fat
8. **What is the term used to describe the alignment of the atoms in the human body once the patient enters the MRI suite?**
   a. Polarization
   b. Vector realignment
   c. Relaxation
   d. Net magnetization
9. **Radiofrequency has what effect on protons?**
   a. It is rejected.
   b. It is absorbed.
   c. It is duplicated.
   d. It is digitalized.
10. **Spin-echo and gradient-echo are two types of what?**
   a. Magnetization
   b. Cardiac pathology
   c. Polarization
   d. Pulse sequences
11. **An absence of signal is called**
   a. flow void.
   b. signal void.
   c. artifact.
   d. wrap-around.
12. **Which is NOT true of cine MRI?**
   a. Cine techniques can be repeated at 20- to 30-msec intervals to image a single slice.
   b. Cine and real-time MRI are the same.
   c. Cine techniques can be used for multiple slices at a large number of consecutive points throughout the cardiac cycle.
   d. Cine MRI can be used in conjunction with myocardial tissue tagging techniques for visualization.
13. **Myocardial tissue tagging is very beneficial for what type of evaluation?**
   a. Assessing wall motion
   b. Assessing regional wall thickening
   c. Both a and b
   d. Neither a nor b
14. **Contrast agent is delivered via what route in cardiac MRI?**
   a. Direct arterial catheterization
   b. Oral ingestion
   c. Inhalation
   d. Intravenously
15. **The common name for a myocardial infarction is:**
   a. Heart attack
   b. Sudden cardiac death
   c. Arrhythmia
   d. Dissection
16. **Which coronary artery bifurcates?**
   a. Right
   b. Left
   c. Brachiocephalic
   d. Innominate
17. **Motion is controlled on cardiac MRI by what?**
   a. Stop-gap imaging
   b. Breath-hold techniques
   c. Freezing the images
   d. Nothing
18. **What is a problem with imaging congenital heart disease in young children?**
   a. Children are terrified of the scanner.
   b. Children are more claustrophobic than adults.
   c. Children cannot tolerate contrast agents.
   d. Children do not follow oral instructions well.

19. Which of the following is true of cardiac MRI?
   a. Nearly every type of cardiac pathology is a candidate for MRI.
   b. Only a small number of possible disease processes can be diagnosed with cardiac MRI.
   c. An allergy to iodine is a contraindication for cardiac MRI.
   d. Cardiac MRI cannot be used for pediatric patients.

20. One of the benefits of cardiac MRI is:
   a. no radiation exposure.
   b. no femoral arterial punctures.
   c. no iodine-based contrast.
   d. all of the above.

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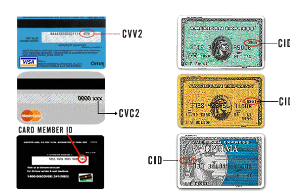

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