# Non-invasive Cardiac Imaging

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**Chest X-Ray**

The chest X-ray provides information about the size and configuration of the heart and great vessels, as well as pulmonary vasculature, and pleural effusions. Cardiac chamber dilation, rather than wall thickening is generally perceived as an alteration in cardiac silhouette. Routinely posteroanterior (PA) and lateral chest films are obtained. Enlargement of the fight atrium may cause bulging of the heart to the fight on the PA film, while fight ventricular enlargement is generally perceived as a filling of the anterior clear space on the lateral film. Left atrial enlargement may be detected by an upward displacement of the left main-stem bronchus, or posterior displacement of the barium filled esophagus on lateral films. Left ventricular enlargement is the most common finding on chest x-ray, generally results in an increased cardiothoracic ratio ($\geq$ 0.50). Pericardial effusions may be suspected by an enlarged cardiac silhouette with "water bottle" appearance. Fluoroscopy, more often performed in the cardiac catheterization suite, generally confirms minimal motion of cardiac borders. Fluoroscopy is also more sensitive for detection of cardiac valve calcium as well as epicardial calcium (see cine CT). The chest x-ray is also helpful to demonstrate upper zone redistribution, pleural effusions, and Kerley B-lines indicative of congestive heart failure.

**Echocardiography**

Echocardiography uses ultrasound to image the heart and great vessels. It is widely regarded as the technique of choice for evaluation of suspected valvular heart disease. Its ease of use, high temporal and spatial resolution, and lack of complications also makes it ideal for assessment of cardiac chamber size and systolic function, though comprehensive left ventricular endocardial borders may be difficult to identify in a significant minority (20%) of patients. Three general types of studies may be performed, M-mode echocardiography, two-dimensional (2D) echocardiography, and Doppler echocardiography. M-mode and 2D imaging are useful for quantifying chamber sizes, ventricular systolic function, wall thickness, and valvular morphology while Doppler echocardiography, which measures blood flow velocity and includes pulsed wave, continuous wave and color Doppler methods, is most valuable for assessing valvular function.

Quantitative data regarding left ventricular wall thickness and chamber dimensions are generally measured using M-mode methods, a technique which uses very high temporal (>1000 Hz) resolution, while qualitative global and regional left ventricular systolic function is generally best appreciated using 2D methods. Automated endocardial edge-detection techniques have recently been introduced for "real-time" analysis of global systolic indices, but these algorithms make many assumptions regarding the ventricular geometry (symmetry) which may not be applicable to the individual patient. Complications of myocardial infarction such as left ventricular aneurysm or left ventricular apical thrombi are readily identified by 2D transthoracic echocardiography. The crescent shaped right ventricle is more difficult to assess, and only qualitative analyses from 2D data are generally used. Left atrial chamber size may also be quantified by 2D transthoracic echocardiography. While left ventricular thrombi are easily appreciated from transthoracic approaches, left atrial thrombi are best visualized using

The physical examination provides a tremendous amount of information we get from that. Just the general appearance of our patients. Is there evidence of peripheral cyanosis? Are they dyspneic? Is there evidence of exophthalmus, the fundi? Again, in patients with hypertension especially diabetes. Looking at jugular venous distension. Examining the carotid pulse. Is it delayed, is there a bi-fib pulse - the bi-fib pulse being suggestive of a hypertrophic obstructive cardiomyopathy? Examining the lungs for rales, effusions. The heart for PMI as well as murmurs. It is important in your patients to have the patients turn in the left lateral decubitus position to hear mitral murmurs and if you are concerned about aortic insufficiency, certainly have them sit up and forward with an exhalation examination. Finally, the abdominal examination - ascites, organomegaly and the extremities.

Remember with murmurs that one can actually increase venous return usually by squatting or decrease venous return by having the patient going to an erect posture and these will affect various murmurs. So, the murmur of the obstructive cardiomyopathy will increase when you decrease venous return, decrease with squatting and increase in venous return. Similarly, mitral regurgitation will increase with squatting. Aortic stenosis increases with squatting, decreases with erect posture and one should certainly perform these maneuvers whenever one can't decide exactly the cause of the murmur or source.

Chest x-rays, still a relatively low technology item. Remember that it can tell us about the heart and great vessels, the configuration of the heart. Is the cardiothoracic ratio greater than 0.5 so that there is evidence of cardiomegaly? Is a specific chamber enlarged? Is there valvular calcification? Though I think that is better appreciated by fluoroscopy. Is there evidence of pericardial calcification, such as in patients with TB or chronic pericarditis? Is there evidence of a widened mediastinum, suggestive of an aortic aneurysm or dissection? The right atrial border forms most of the right heart, then the ascending aorta, aortic arch, then the transverse, the start of the descending thoracic aorta, pulmonary artery, a little bit of the left atrium, a left atrial appendage followed by the left ventricle.

This is the typical "water bottle" appearance and the patient has a very large pericardial effusion or early tamponade physiology. Again, note loss of defined cardiac contours. When you see this "water bottle" appearance one should be concerned that the patient has a pericardial effusion. The chest x-ray that shows predominance of the left atrium right and a slightly dilated left ventricle in a patient who has severe mitral regurgitation with left atrial enlargement.

The most commonly used noninvasive imaging technique is probably transthoracic echocardiogram. There are approximately 6 million cardiac ultrasounds done annually in the United States. It is very, very helpful. One can look at the left atrium. Measuring both its width, length and area and volumes. It is not very good for looking at thrombi, so one should not use transthoracic or surface echo for looking at left atrial thrombi. That is because thrombi are found in the left atrial appendage, an area that is poorly seen by transthoracic approaches. You can very nicely look at the left ventricle - look at wall thickness. Is there evidence of hypertrophy in your patients with hypertension? Is there evidence of ventricular chamber enlargement in your patients with valvular insufficiency? Is there regional or global systolic dysfunction? Are there aneurysms? Are there apical thrombi in the left ventricle? Right atrium, we are not as good at looking at by transthoracic echo, but it is pretty good for area and length. We can tell qualitatively if there is mild, moderate, severe dysfunction. Is it enlarged or normal? But we have a difficult time doing quantitative analyses of the right ventricle.

The transthoracic surface approach is very good for looking at an aneurysm of the proximal aorta, not very good for looking at dissections. So, if you want that, you need to get a TEE, MRI or CT. Again, transthoracic echo is very good for looking at pericardial effusions. It is not very good for looking at pericardial thickening or calcification. For that, again, I would get an MR or CT. Transthoracic echo is also very good for looking at the valvular lesions. How many leaflets does your aortic valve have? Are they mobile? Are they stenotic? Are there vegetations? Are there abscesses? TEE allows better definition of vegetations and abscesses but transthoracic echo is often transesophageal echocardiography (TEE; see below). Pericardial effusions are readily identified by surface echocardiography. A transthoracic echocardiogram should be considered the technique of choice for the emergent evaluation of suspected pericardial effusion.

Assessment of valvular heart disease is the "bread-and butter" of echocardiography, and the need for confirmatory cardiac catheterization for many of these lesions has recently been questioned. Mitral stenosis, most commonly the result of rheumatic heart disease is characterized by leaflet thickening, calcification, and immobility. Mitral valve area may be assessed either by direct planimetry or Doppler assessment of the pressure half-time, (time needed for the pressure gradient across the mitral valve to decrease by 50 percent). The longer the pressure half-time, or the longer it takes for the gradient across the mitral valve to fall, the smaller the mitral valve area. Mitral regurgitation, either in association with mitral valve prolapse, chordal rupture, or ischemic papillary muscle dysfunction is readily evaluated by both pulsed wave and color Doppler techniques. Color Doppler, in which direction and velocity of blood flow are encoded by color images superimposed on 2D images of the heart, is very sensitive for ' the detection of valvular insufficiency. Over half of clinically healthy patients will have a small amount of mitral regurgitation detectable on color Doppler examination. The clinical relevance of this finding, in the absence of structural mitral valve disease, is uncertain. Small amounts of tricuspid and pulmonic insufficiency are also common, and generally not considered pathologic conditions. In contrast, even mild amounts of aortic insufficiency are quite unusual in the "healthy" population, and this finding is therefore highly suggestive of underlying valvular pathology. Subvalvular, valvular, and supravalvular aortic stenosis are also readily detectable using combined 2D and Doppler techniques. Pressure gradients across stenoses may be estimated by applying the modified Bernoulli equation:

$$\text{Pressure} = 4\,[\text{velocity}]^2$$

In the setting of normal left ventricular systolic function, aortic gradients exceeding 4 cm/sec (pressure gradient > 64 mmHg) indicate severe aortic stenosis (aortic valve area < 0.7 cm2). The absence of such a high gradient does not exclude the diagnosis. A much lower gradient may reflect severe aortic stenosis in the setting of a depressed cardiac output. Aortic valve area is best estimated by applying the Continuity Equation to Doppler data from left ventricular outflow tract and aortic valve:

$$\text{AoVA} = [A_{LVOT} \times V_{LVOT}] / V_{AOV}$$

AoVA = aortic valve area

$A_{LVOT}$ = Area of LV outflow tract (determined from LVOT diameter)

$V_{LVOT}$= Velocity of LV outflow tract (measured by pulsed Doppler)

$V_{AoV}$ = Velocity through the aortic valve (measured by continuous wave Doppler)

The presence and severity of aortic insufficiency may be estimated using Color Doppler or pressure half-time techniques. For this condition, a shorter pressure half-time suggests a more "rapid" equilibration of central aortic and left ventricular diastolic pressures and more severe aortic insufficiency. Pressure gradients across prosthetic valves may also be readily appreciated by Doppler techniques, though there is considerable acoustic shadowing with mechanical prostheses which limits evaluation of prosthetic valve

sufficient in certain patients. For looking at mitral valve prolapse and rheumatic mitral stenosis, the transthoracic echo is very good, and, for looking at the pulmonic and tricuspid valve mobility and vegetations, it is also generally adequate.

Rheumatic deformity of the mitral valve. When you see that listed on the cardiographic report, what that means is the echocardiographer has seen a "hockey stick" appearance of the anterior mitral leaflet with relative immobility of the posterior leaflet. This is very characteristic of rheumatic disease. One can also use the parasternal long axis approach to look at pericardial effusions. This is an example of a patient who has a relatively large posterior, relatively echolucent pericardial effusion. One can also look in the parasternal short axis which is an orthogonal view to the one I have just shown you where in fact the left ventricle appears as a donut. What we generally describe is this is the right ventricle so this represents the interventricular septum. This is the inferior wall, the posterior wall, the lateral wall and the anterior wall and one can easily describe regional and global left ventricular systolic function.

One can also look from the apical four-chamber view where now we have again left ventricle, right ventricle is labeled and the left atrium is filled with a mass which represents a myxoma herniating through the mitral orifice. This is very easily seen by transthoracic echo. However, if one is worried about very small myxomas, you might miss this on a transthoracic approach but this one is very large. One wouldn't miss this. If one is considering what is the ability of transthoracic echo for looking at left ventricular thrombi, it is very good. The overall sensitivity has been estimated at between 80 and 95%. It is typically in the patient who is having an anterior apical myocardial infarction within the past week or two or a severe dilated cardiomyopathy.

One can finally look at the subcostal view where in fact this is the liver, here is the heart. One can appreciate the left atrium, the right atrium and the interatrial septum which has fallout here in the 2-D examination in a patient with a relatively large atrial septal defect in color Doppler which shows prominent flow going across here. This is also the preferred orientation to look for pericardial effusions and the reason for that is when one is doing a percutaneous pericardiocentesis, the needle usually approaches the heart from this orientation so we look at how much fluid, if any, is anterior to the right ventricle right here. This example shows no pericardial effusion. Again, one can use transthoracic echo to look at global as well as regional systolic function and also qualitatively at the right ventricular systolic function.

One can also combine transthoracic echo with physiologic or pharmacologic stress. Reports have shown that transthoracic echo with stress has an overall sensitivity and specificity for multi-vessel disease exceeding 90% and probably equivalent to radionuclide studies. However, I would caution you that not all echos are equally good to radionuclide assessment in all patients. In general, the patient who has good echo windows and has normal left ventricular systolic function at rest is the best candidate for an exercise echo.

In addition to imaging using 2-D or M-mode echocardiography, a transthoracic echo is also very good using Doppler for assessing valvular stenoses. What we do is we convert the velocity of blood across the valve to pressure gradients. In general, in the presence of normal systolic function, normal cardiac output, if the gradient across the aortic valve exceeds 4 meters/second or 64 mmHg, there is severe aortic stenosis.

One can also use Doppler to measure the significance of mitral stenosis using a pressure half-time.

One can also use color Doppler and that is primarily used to look at valvular insufficiency. We use this to look at qualitative assessment of insufficiency - mild, moderate and severe. In general, we look at the receiving chamber, for example the left atrium, and if the color velocity jet encompasses the proximal third, we would say there is mild mitral regurgitation. The proximal half, it would be moderate and if it goes all the way back, is relatively broad with reversal of flow in a pulmonary vein, we would say there is severe mitral regurgitation. I think you can all appreciate this is a very qualitative approach.

Remember that it is semi-invasive. It is actually considered moderately invasive. It is a modified endoscopy. It uses a very flexible probe of approximately 100 cm in length. It is a nonvisualization port so it is placed blindly in the esophagus. You can use much higher frequency transducers, typically 5 or 7.5 MHZ transducers, which allow enhanced spatial resolution. We can see very fine details. But one shouldn't think of it as simply a better echo. It is better for looking at structures which are very close to the esophagus.

insufficiency. The latter limitation is especially problematic for mitral valve prostheses, and transesophageal echocardiography is far more successful for evaluating these patients. Finally, transthoracic echocardiography is also helpful for identifying congenital heart disease in the adult, such as atrial septal defects, bicuspid aortic valve, aortic coarctation, etc. The sensitivity of echocardiography for identifying an atrial septal defect or patient foramen ovale is increased by the use of intravenous injection of agitated saline or sonicated albumen (Albunex®).

The ability of surface echocardiography to visualize the left ventricle and assess regional systolic function has led to its development as an assessment of systolic function in combination with physiologic (treadmill/bicycle) or pharmacologic (dobutamine) stress. The normal response of myocardium to increased physiologic demand is augmentation of regional systolic function and decrease in ventricular volumes.

Induction of abnormal regional contraction (lack of augmentation, new hypokinesis, akinesis or dyskinesis) is indicative of regional ischemia. Left ventricular cavity dilation may suggest a global process (ischemia or other). In the setting of good imaging windows, and the combination of echocardiographic imaging with stress has a sensitivity/specificity similar to that of radionuclide imaging, generally at a lower cost.

Radionuclide imaging is superior in the setting of baseline wall motion abnormalities or situations in which the echo imaging windows are limiting.

In the late-1980's, transesophageal echocardiography (TEE) was commercially introduced in the United States. Due to the proximity of the esophagus to the heart and thoracic aorta, and lack of interposed lung or bone, higher frequency transducers may be used, allowing for superior spatial resolution. Indications for TEE include: inadequate transthoracic studies (especially post-thoracotomy or ventilated patients), suspected aortic dissection, endocarditis with vegetations and/or myocardial abscess, suspected left atrial thrombi/tumor (in patients prior to cardioversion of atrial fibrillation), evaluation of prosthetic valve function (especially mitral prostheses), atrial septal defect/patent foramen ovale, intra-operative assessment of mitral valve repair/replacement, or suspected cardiac source of embolism. Esophageal intubation is readily achieved in over 98% of patients and complications are quite rare and generally related to sedation. Multiplane technology in which a set of crystals may be rotated through at $180^0$ arc has permitted superior assessment of many conditions and is the standard of many laboratories.

Radionuclide Imaging

Radionuclide ventriculography (RVG) or MUGA uses technetium 99m labeled red cells to delineate cardiac chambers. The first pass technique also allows for identification of intracardiac shunts while the equilibrium method records from at least two views and averages data over several minutes to give an estimate of global ejection fraction. Scintigraphic data is corresponding to individual "frames" within a cardiac cycle may also be analyzed in cine format to give qualitative information regarding regional wall motion (both at rest and with stress). Semi-quantitative techniques may be applied to determine ventricular chamber filling dynamics, though typically RVG data is utilized to determine global ejection fraction (EF):

EF = [(end-diastolic counts) - (end-systolic counts)]/(end-diastolic counts).

Indications for TEE are generally about 7% of all transthoracic examinations in most laboratories. It is evaluation of the aortic dissection or aneurysms; prosthetic valves especially in the mitral position; evaluation of patients with suspected source of emboli, patent foramen ovales atrial septal aneurysms, left atrial appendage thrombi; looking for endocarditis and abscesses and that is primarily because we can see smaller vegetations. It may be used for guidance of early cardioversion of atrial fibrillation for patients who don't have atrial thrombi and sometimes used especially in the patient who is intubated, assessing left ventricular systolic function.

Many different authors have looked in studies looking at surgical and autopsy examples of transthoracic versus TEE evaluation for the presence or absence of vegetations and most have actually shown, I think as you would expect, that TEE is superior but it is not perfect. There is a sensitivity of about 80 to 90% for vegetations as well as abscesses.

TEE is also exquisitely good for looking at aneurysms of the atrial septum as shown here - this bulging into the right atrium which often flips back and forth. As you know, 70 to 80% of the time these are associated with patent foramen ovale or atrial septal defects. They are generally detected with the use of TEE and agitated saline injection where we see a few microbubbles pass across from the right atrium to the left atrium.

Again, there have been many studies that have looked at our ability of transthoracic versus TEE for identifying atrial septal defects, primum, secundum and sinus venosus defects. In general, primums are easily seen by both approaches. However, secundum and sinus venosus are much better appreciated by TEE. Certainly PFOs are also much better appreciated by transesophageal echo with saline contrast. One can often, at times, actually identify a thrombus in transit as shown here right across the patent foramen ovale. One can also use TEE to look for masses in the left atrium. An example of a myxoma. This typically helps the surgeon guide his therapy or surgical approach but the mass itself would be easily appreciated by transthoracic approaches.

Finally, one can use TEE to look for a left atrial appendage thrombi. The left atrial appendage is not well seen by transthoracic echo. It is very well seen by TEE. These are examples three different thrombi easily seen by TEE which would not be seen by the transthoracic approaches. There have now been many studies which have looked at the ability of TEE to identify thrombi, all showing, in fact, that it is very accurate with sensitivities exceeding 90 to 95% and no false negatives. TEE, in contrast, is relatively poor with sensitivity of only about 40 to 60%. Again, these are the autopsy or surgical confirmation TEE studies.

Finally, if you are concerned about a thrombus in the right atrial appendage, right atrial appendage cannot be seen on the transthoracic echo. It is only seen by TEE.

Moving on to radionuclide imaging techniques. One can first label the red cells, give them back to the patient, scan over the lung field and look for early recirculation indicative of an intracardiac shunt as shown here in the normal. One sees prominent enhancement followed by normal systemic recirculation and enhancement again. More commonly, one uses radionuclide techniques to estimate ejection fraction. I would say that radionuclide ventriculography is probably the best reproducible quantitative technique to get a number of what the ejection fraction is. It is highly accurate within 3 to 5%. However, it isn't very good for looking at regional function. It is good for giving you a global estimate of ejection fraction. It is not as good at looking at regional wall motion. If your question is, "What is the anterior wall doing?" I think echocardiography is probably the preferred technique.

More commonly, one uses radionuclide imaging in combination with pharmacological physical stress to look for myocardial perfusion. Remember that thallium is an analogue of potassium. It is taken up by viable myocytes. Technetium 99, Sesta-MIBI in fact looks at perfusion. They are slightly different.

Indications for exercise tests with radionuclide or 2-D echo imaging includes the following. If, in fact, there are EKG abnormalities at rest which make it impossible to, in fact, determine the significance of further ST abnormalities; if the patient has a bundle branch block; if they are on digoxin; if there are suspected false positives because, in fact, the patient has few risk factors; or if, in fact, the question is viability, one can combine dobutamine with echo to look at increased contractility at low dose dobutamine at 2.5 or 5 mcg with then depressed function or dyskinetic segments at higher dose dobutamine. That, in fact, suggests viability and improved function with revascularization.

Again, echo versus nuclear. One should use the echo if there are good echo windows and there is normal resting systolic function or, in fact, you are looking at viability and

The technique is accurate to +5% and is considered the best clinical test for quantitation of global left ventricular ejection fraction.

Radionuclide techniques are more commonly used for assessment of regional myocardial perfusion. For many years, thallium 201, an analog of potassium was the most commonly used agent. Its uptake by viable cardiocytes is proportional to regional myocardial blood flow. Areas of myocardial necrosis, fibrosis, and or relative ischemia show reduced thallium uptake, or "cold spots" as compared with normally perfused regions. Resting thallium data has also been used to define "viable" myocardium in areas of resting hypo or akinesis on wall motion analysis. More recently, technetium 99m Sesta-MIBI, has been used to assess regional myocardial perfusion. Advantages of this agent as compared with thallium-201 are on-site availability, improved signal:noise, shorter half-life, and ability to combine first pass imaging for assessment of left ventricular systolic function with subsequent imaging for regional myocardial perfusion. Redistribution of Sesta-MIBI is minimal, allowing for scanning to be performed up to 6 hours after injection. This makes it an ideal agent for assisting in the evaluation of the patient with atypical pain. Sesta-MIBI may be injected during a period of chest pain with elective scanning to assess myocardial perfusion performed at a later date.

Pyrophosphate labeled with technetium 99m may be used to assess patients with suspected transmural myocardial infarctions in whom the ECG is difficult to interpret (i.e. left bundle branch block) or those with a clinical presentation too late to show enzymatic elevation. Scans are most likely to be positive if performed 2-3 days after infarction. Another option for the identification of acute myocardial infarction in such patients is the use of radiolabeled fragments of antimyosin antibodies.

While planar radionuclide imaging was commonly used, single photon emission computed tomography (SPECT) imaging has become more common and is standard in many laboratories. SPECT allows for tomographic images and better localization of smaller/focal deficits.

Cine or ultrafast CT

While not directly visualizing the coronary arteries, several centers are now using ultrafast or cine CT as a means of detecting and quantifying coronary artery calcium. Coronary artery calcification is both a sensitive and a specific marker for the presence of coronary artery atherosclerosis with increased calcified plaque volume in patients with obstructive coronary lesions as compared with asymptomatic subjects. Unfortunately, not all obstructive lesions have detectable calcium within the atherosclerotic plaque and epicardial calcium deposits are commonly seen in apparently healthy men over 50 years and women over 60 years. Screening for epicardial calcium to identify asymptomatic patients with coronary artery disease is currently not recommended by the American Heart Association or American College of Cardiology. Cine CT may also be used to assess regional myocardial perfusion by imaging the heart during intravenous bolus infusion of iodinated contrast. Limited data are available at the present time, and considerable contrast is needed for a sufficient signal to noise ratio.

Magnetic Resonance Imaging

Magnetic resonance (MR) imaging is ideally suited for evaluating the heart with excellent soft tissue discrimination and the ability to acquire both static and dynamic images of the heart in double-oblique, true tomographic planes. While the clinical potential of MR for the evaluation of the cardiovascular system has been recognized for over a decade, few clinical indications exist

you are just looking at low dose dobutamine. Nuclear is better if there is abnormal resting systolic function or there is an irregular contraction pattern, specifically left bundle branch block, pace rhythms or atrial fibrillation.

MR is probably the best technique we have for evaluating the entire thoracic aorta. It can be recorded very rapidly. In contrast, in the coronal plane, this is an example of an aortic dissection. If the patient is hemodynamically unstable, then I think the TEE is the preferred approach to diagnose or exclude aortic dissection.

MR is a very good technique for looking at pericardial thickening when there is a question of constriction. MR is also very good for looking at right ventricular dysplasia - a fatty infiltration of the right ventricle. MR is very good for looking at congenital heart disease - complex congenital heart disease but also simple congenital heart disease.

I think in the next year or two you are going to see noninvasive MR coronary angiography. No needles, no IVs, no contrast. The patients don't have to do anything except hold still for about 8 minutes. This probably will be available in the next couple of years for specific patient populations.

If you are looking at chamber sizes, I think echo is probably best and MR. If you are looking at myocardial mass, again, it is echo and MR. If you are looking for intracardiac masses, it is going to be echo, specifically TEE. For valvular disease, echocardiography using continuous wave and color Doppler techniques. If you are looking at left ventricular systolic function, I think echo, radionuclide techniques and MR are all good. If you are looking at RV systolic function, again, I think MR is the best. We don't get a good look at the right ventricle with echocardiography. RVG is probably okay but has more problems with right ventricular function. If you are looking at blood flow, I think that also would probably be in the realm of radionuclide techniques or potentially MR.

today, partly related to the relative high cost of MR imaging as compared with more conventional technologies such as echocardiography and radionuclide imaging. In both animal and human studies, MR has proven to highly accurate for the assessment of left and right ventricular mass, left and right ventricular volumes, as well as global and regional left ventricular systolic function. Standard cine gradient-echo MR methods have also been shown to be accurate for the qualitative evaluation of valvular insufficiency. Phase velocity MR may allow for quantitation of valvular insufficiency or stenoses. In clinical cardiology, MR has proven most helpful for the assessment of disease immediately adjacent to the cardiac chambers, including evaluation of the thoracic aorta for an aneurysm or dissection, identification of pericardial thickening, and for appraisal of complex congenital heart disease. More recently, high resolution MR angiographic techniques which allow for coronary artery imaging have become available and appear very promising, but remain investigational. While physical exercise within the confines of the magnet are difficult. MR assessment of regional myocardial perfusion by combining pharmacologic stress with the intravenous administration of an MR perfusion agent and assessment of first-pass kinetics of the agent as it perfuses the left ventricular myocardium are also being investigated. It is premature to advocate MR imaging for coronary artery or myocardial perfusion imaging, though it is likely that if MR coronary angiographic techniques are successful, that MR assessment of function and perfusion will be quickly embraced and cardiac MR will become the dominant imaging technique for the evaluation of the patient with suspected ischemic heart disease.

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