Contrast Use in CTA Applications

Cardiac CT: Beyond the coronary arteries

Multidetector CT is an increasingly powerful tool for imaging thoracic aortic disease, pericardial disease, cardiac masses, valvular disease, and nonischemic myocardial disease. In many cases, CT is now sufficiently advanced to interrogate lesions that previously were described only on MR.

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At the Cleveland Clinic Foundation, noninvasive cardiovascular imaging is collaborative and multidisciplinary. We have brought together the departments of Radiology, Cardiac Surgery, and Cardiovascular Medicine into one common effort to promote cardiovascular computed tomography (CT), magnetic resonance (MR) imaging, and other noninvasive cardiovascular imaging techniques.

In 2004, we examined nearly 6600 patients by cardiovascular multidetector CT (MDCT) and nearly 2000 patients by cardiovascular MR. Fifty-six percent of studies in each category involved patients with thoracic aortic disease. Myocardial disease was the primary indication for another 20% of MR patient studies and 2% of CT patient studies, pericardial disease for 9% and 2% of MR and CT studies, respectively, and cardiac mass for 3% and 1% of MR and CT studies, respectively. This article will discuss each of these indications.

CT versus MR

There is no single image acquisition protocol for cardiac CT, as this technique is used to examine a vast array of disease processes. Often, however, the protocol is a variation of that used for coronary MDCT angiography.

With our 64-detector cardiac CT scanner, rotation time is 330 msec, yielding a temporal resolution of 83 to 165 msec. The 0.6-mm detector collimation yields high, submillimeter (0.4 mm) isotropic spatial resolution. Full coverage of the heart can be accomplished in 10 to 12 seconds.

We use pulse modulation whenever possible to reduce the patient’s radiation exposure. Unless it is contraindicated, we control the heart rate with beta-blockers, intravenously injecting metoprolol in 5-mg doses, up to a total of 6 doses. We also give patients 0.3 mg of nitroglycerin sublingually whenever possible to dilate the coronary arteries.

We generally prefer to use a high-concentration contrast agent (370 mgI/mL), but because of the high incidence of renal insufficiency and diabetes in patients undergoing cardiovascular CT, we often use iodixanol 320 mgI/mL instead. We inject 50 to 70 mL of contrast material at 5 to 6 mL/sec, followed by a 30-mL saline flush, and use automated bolus tracking to time image acquisition.

A variety of postprocessing techniques are useful in the interpretation of the cardiovascular MDCT data set, including transaxial slices; multiplanar reconstructions, both straight and curved; thin maximum-intensity projections (MIPs), straight and curved; volume-rendered reconstructions; and 4-dimensional (4D) reconstructions. The selection of specific postprocessing techniques is directed by the physician and depends on the clinical question at hand.

As impressive as state-of-the-art technology CT is, it is worth noting that less sophisticated technology is sufficient to perform meaningful cardiac CT studies in many cases.

Thoracic aortic disease

CT plays a vital role in several disease processes that have symptoms that mimic coronary disease. Suspected aortic dissection, for example, is a common indication for cardiovascular CT in patients with chest pain, along with coronary disease and pulmonary embolism. Three-dimensional acquisitions offer the physician a great advantage in interfacing with the data and determining whether the aorta is, in fact, dissected.

In addition, CT has an advantage over MR and other techniques in its reproducibility. Patients with a noncommunicating dissecting intramural hematoma of the thoracic aorta return for imaging time and again. CT gives us the benefit of appreciating better acute bleeding in the wall of the aorta because of the inherently high attenuation of blood collections, and of following the blood products and the evolution of the dissection process consistently over time.

Both MR and CT are useful in imaging patients who may undergo stent-grafting for aortic dissection (Figure 1).
or other forms of aortic disease, such as acute rupture or aneurysm. Prior to stent-grafting for a type B aortic dissection, MR enables appreciation of both turbulent flow due to the compressive effect of the false lumen, and the markedly compressed-appearing true lumen. As it is difficult to image through the stent-graft with MR, multidetector computed tomography is better suited for visualizing the staged stenting procedure and the complete obliteration of the false lumen. Post-Rx = post repair.

CT also has an advantage over MR in evaluating aortic root aneurysms. Current 64-detector CT technology enables interrogation of a saccular aneurysm at the aortic root and even enables appreciation of communication with the right ventricular (RV) outflow tract or proximal main pulmonary artery (MPA).

In a patient with dull chest pain, a finding on CT of voluminous thickening of the aortic wall is suggestive of aortitis, a condition that may cause myocardial infarction (MI) or stroke. Traditionally, MR has been used to further evaluate the cause of wall thickening, with short tau inversion recovery (STIR) imaging techniques reflecting water content, but not necessarily disease activity. Therefore, we often now take a new approach that combines CT with fluorodeoxyglucose (FDG) positron emission tomography (PET) on a hybrid system. In Figure 2, accumulation of FDG in the thickened wall confirms a metabolically active process—aortitis—rather than intramural hematoma.

**Pericardial disease**

Inflammatory pericarditis can be diagnosed equally well by either CT or MR. A 16-detector CT scanner is sufficient to detect inflammation of the visceral and parietal pericardium, and to demonstrate stranding, which signals an active pericardial process. Moreover, the use of older technology can reduce radiation exposure to the patient.

Constrictive pericarditis has long been diagnosed by CT. Even a 4-detector CT scanner is able to reveal whether the pericardium is markedly calcified and thickened. It is not, however, as capable of physiologic assessment, which is important in making the diagnosis of constriction and determining whether the patient needs surgical intervention, such as stripping.

We have traditionally relied on MR, often in concert with echocardiography, to detect abnormalities in ventricular filling. However, 64-detector CT technology enables excellent visualization of the calcified pericardium. In Figure 3, the thin MIPs clearly show a shell of calcium surrounding the heart. On volume reconstruction, there is complete encasement of both ventricles by a thick rind of calcified pericardium, which predisposes to constriction, but does not necessarily indicate constrictive pathophysiology.

With the same level of CT technology and 4D reconstructions, for the first time we are able to see the physiologic component of the disease process. Abrupt limitation of ventricular filling as well as a diastolic septal bounce clearly indicate that there is a functional problem with the pericardium. In a symptomatic patient, such CT findings are sufficient to indicate the need for surgery.

**Cardiac masses**

The term cardiac mass encompasses a vast group of conditions, both benign and malignant. In patients with atrial fibrillation who are preparing to undergo pulmonary vein isolation, CT sometimes demonstrates incomplete opacification of the left atrial appendage. This finding suggests left atrial appendage thrombus. In
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Some cases, however, what appears to be a clot-related filling defect on CT is found to be nothing more than sluggish flow on transesophageal echocardiography. This discrepancy suggests the need for an intravascular CT contrast agent that would enable imaging after equilibration, rather than during a first-pass phase. Some mobile masses are better seen with CT than with MR, because of the ability of dynamic CT to appreciate the filling defect. On cine MR, there may be only vague evidence of a cystic lesion attached to the papillary muscles, for example, whereas it will be clearly seen as a mobile mass on dynamic CT.

Myocardial fibroma offers an example of the benefits of evaluating a patient with both CT and MR. CT may show a mass with calcification, suggesting a benign lesion, such as a fibroma. Very tailored, edema-weighted MR imaging can determine that there is no brightening, which would indicate a more aggressive edematous process. An affinity for gadolinium on delayed-enhancement MR confirms a fibrotic-type lesion.

Lipoma is easily diagnosed by either CT or MR. With MR, we have the advantage of being able to saturate the fat signal and confirm that a mass is simply a lipoma. Sometimes, however, what appears to be a simple lipoma on MR is more worrisome when evaluated by CT. Figure 4 demonstrates stromal enhancement in an atrial lesion that appeared benign on MR, a worrisome finding that indicates tumor neovascularity.

Just as an apparent lipoma may in fact be liposarcoma, suspected constrictive pericarditis may instead be pericardial lymphoma. Figure 5 offers another example. A patient who underwent CT for evaluation of coronary artery bypass graft patency was shown to have a mass-like lesion of the right ventricular cavity. Careful observation showed an area of enhancement, suggesting a blood supply to the mass. Dynamic reconstruction showed the mass to be very large and fixed to the anterior wall. On further investigation, CT revealed a very aggressive-looking lesion of the left kidney, compatible with a metastatic hypernephroma.

Valve Disease

Evaluation of valve disease is largely dominated by echocardiography. Nonetheless, we can gain a great deal of information from CT, even if the study is being done for another reason. It is common to be able to appreciate calcification and thickening of mitral leaflets in a patient with mitral stenosis, for example. Similarly, during aortic imaging, we can often see that an aortic valve is calcified and immobile.

An unanticipated new application of CT is the evaluation, prior to surgery, of...
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FIGURE 3. (A and B) In a patient with constrictive pericarditis, the thin maximum-intensity projections clearly show a shell of calcium (arrow in A) surrounding the heart. (C) On the volume reconstruction, there is complete encasement of both ventricles by a thick rind of calcified pericardium, which predisposes to constriction.

FIGURE 4. (A and B) Stromal enhancement on CT in an atrial lesion (arrows), which appeared benign on MR, is a worrisome finding that indicates tumor neovascularity and suggests a diagnosis of liposarcoma, rather than simple lipoma.

FIGURE 5. (A) During a multidetector CT evaluation of coronary artery bypass graft patency, (B) a mass-like lesion (red circle) of the right ventricular cavity was noted. (B and C) The area of contrast enhancement at its contact with the right ventricular wall suggests a blood supply to the mass. An aggressive-looking lesion of the left kidney on a subsequent CT image stack revealed a metastatic hypernephroma.
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patients with valvular vegetations that preclude catheter angiography. Figure 6 shows a patient with an aortic valve vegetation who was preparing to undergo aortic valve surgery with coronary artery bypass grafting if necessary. In the absence of selective coronary angiography, the surgeon must plan the surgical approach relying on intraoperative palpation of the coronary arteries. The potential dangers of coronary catheterization include vegetation dislodgement with subsequent embolization. In this patient, 64-detector coronary CT angiography identified the need for bypass grafting in multiple coronary sites and the best graft insertion points.

CT is also being used in front-line assessments of novel therapies. For example, CT can aid in evaluating the efficacy of composite tricuspid valve-stents in patients with ascites from severe tricuspid regurgitation who are unable to undergo open-chest surgery because of coexisting illnesses, such as emphysema.

Nonischemic myocardial disease

Nonischemic myocardial disease incorporates a number of conditions, including dilated, hypertrophic, and restrictive cardiomyopathies, and arrhythmogenic right ventricular dysplasia (ARVD).

Even in the days of 4-detector CT scanners, we appreciated the ability of

FIGURE 6. (A) An aortic valve vegetation (arrow) in a patient preparing to undergo coronary artery bypass grafting precludes invasive coronary angiography. (B, C, and D) Rather than planning the surgical approach by palpating the coronary arteries alone, the surgeon was able to rely on coronary multidetector computed tomography to identify needed bypass graft termination points.
CT to evaluate ARVD. Diagnosis of ARVD is still a leading application of cardiac MR, but CT easily depicts its classic signs: An enlarged right ventricle, marked thinning of the right ventricular wall with fatty replacement, and aneurysmal outpouching of the thinned myocardium (Figure 7). Moreover, CT can be performed in a patient with an implantable cardioverter-defibrillator, whereas MR cannot.

Because of the power of the CT, we have changed our approach to the assessment of patients with suspected ARVD. Early on, we realized that CT could quickly assess the cardiac anatomy and determine whether the patient might have ARVD. We were able to bypass an hour-long MR examination and go quickly from a 10-minute CT study for anatomic definition to a 15-minute dynamic MR study to confirm or rule out the diagnosis in equivocal cases. Now, and especially if there is a contraindication to MR, we can completely evaluate the patient, with CT adding dynamic reconstructions. This combined approach enables us to make the diagnosis much faster and perhaps even with greater confidence.

**FIGURE 7.** (A through C) In a patient with arrhythmogenic right ventricular dysplasia, multidetector computed tomography shows an aneurysm in the region of the right ventricular outflow tract (blue arrows), a scalloped appearance to the right ventricular wall, and fatty replacement of the ventricular wall (red arrows). (D) A dynamic reconstruction reveals associated ventricular dysfunction.

**FIGURE 8.** Side-by-side (A) MR and (B) multidetector CT images of a patient with chronic Loeffler’s myocarditis. Both MR and CT show the truncated, filled-in appearance of the apices of the right ventricular cavity (red arrows) and the left ventricular cavity (blue arrows), but CT also depicts calcification, which confirms that the condition is chronic.
CT is now sufficiently advanced to be used to interrogate lesions that previously were described only on MR—for example, a small outpouching of the right ventricular outflow tract that may be responsible for right ventricular outflow tract tachycardia. Today, CT is capable of making such subtle diagnoses and directing therapeutic interventions.

Idiopathic dilated cardiomyopathy is generally evaluated by echocardiography. In some cases, however, CT plays a complementary role by evaluating the patient for coronary arterial plaque and confirming a nonischemic etiology.

In patients with hypertrophic cardiomyopathy, CT clearly depicts abnormalities in gross anatomy, including the asymmetric septal hypertrophy that characterizes this condition. CT also shows changes in the coronary arteries, such as prominent septal perforators feeding the enlarged muscle mass.

There is an ongoing evolution in the evaluation of restrictive cardiomyopathy, from the use of CT to depict anatomy and MR to assess function, to greater reliance on CT alone. With the advent of 4D reconstructions, CT could provide almost all the information we need. Figure 8 shows side-by-side MR and CT images of a patient with chronic Loeffler’s myocarditis. Both MR and CT demonstrate the truncated, filled-in appearance of the apical portions of the ventricular cavities, but CT also depicts the calcification that confirms a chronic condition.

**Ischemic myocardial disease**

Even with 2-detector spiral technology, CT was able to demonstrate at least vague evidence of acute MI that was later confirmed on invasive angiography. Technological advances have improved visualization, but CT still does not come
close to challenging MR, which reliably demonstrates contrast hyperenhancement in areas of infarction.

Recently, Koyama et al1 evaluated the ability of 2-phase, contrast-enhanced multidetector CT to predict left ventricular function and wall thickness in patients with acute MI who were treated with reperfusion therapy. They found that an early perfusion defect, followed on delayed imaging by a residual perfusion defect and hyperenhancement, identified patients who on intermediate and long-term follow-up would develop significantly more myocardial thinning and worse left ventricular function. Such findings, while intriguing, must be examined with caution. The role of advanced CT technology in the assessment of patients with acute MI should be carefully considered.

In patients with chronic ischemia and subendocardial scarring, it is difficult to rival the information available from MR. In Figure 9, delayed enhancement on MR clearly shows multiple infarct zones. Companion CT images show a discrete infarct, with myocardial thinning and some hypoperfusion, but the findings are not as pronounced as in the corresponding MR ranges. MR has also long been able to show very thin subendocardial layers of myocardial scarring, compatible with the small-vessel disease that might be found in diabetes. By comparison, CT is able to offer only a vague sense of the same disease process.

Nonetheless, if one needs to simply delineate the consequences of infarction, CT clearly shows post-MI left ventricular aneurysms and enables functional assessment, confirming dyskinesia in the area of thinning.

Conclusion

CT is being called upon to perform an increasing number of cardiovascular studies. The rapid acceptance of cardiovascular CT is making it a mainstay for the diagnosis of complicated cases, often in combination with other imaging modalities.

The advantages of CT over MR include better spatial resolution, better identification of calcification, and better detection of acute hematoma. In addition, CT enables simultaneous evaluation of the lungs, mediastinum, and abdomen, with the ability to add such examinations onto the cardiac study, as needed, while the patient is still on the table. Moreover, CT is not hampered by considerations that contraindicate or confound MR, such as implantation with a pacemaker or other metal device, or claustrophobia. Finally, cardiac CT is very powerful. Although it is best applied at its highest level, midlevel technology offers clinically useful results in many cases.

Reference


Discussion

ELLIO T. FISHMAN, MD:

Thank you very much, Rick. That was terrific. Are there any comments?

STEPHAN ACHE N BAC H, MD: I noticed all of your images had nice enhancement of the right ventricle and of the right heart, even in those few examples that you said were originally done for coronary assessment or bypass assessment. Some people say, “I don’t want to use all of that contrast bolus because I don’t need enhancement both in the right and in the left heart.” Do you inject a little more or a little longer so you have better assessment of the right heart—so you have enhancement in both?

RICHARD D. WHITE, MD: I wouldn’t consider it a consistent strategy. At times, certainly there is more than one issue, and we have to cover more bases. Sometimes, the patient’s function is just so bad that it’s hard to deliver as precisely as we can in a healthy coronary case. We’re dealing with some pretty sick patients. Sometimes, it’s patient-dependent and sometimes it’s dependent upon us. So it’s a mixture. I wouldn’t say it’s a consistent strategy.

J. JEFFREY CARR, MD, MSCE: I’ve been surprised at the misassignment to various chambers and where things are based on the limited history we often have. One of the strategies that we use if they come in with the concern of a cardiac mass, particularly an atrial mass, I’ll often do the CTA with either no or very poor opacification of the right heart with the flush, and then do an immediate delay scan using our coronary calcium protocol during the equilibrium phase. This works well for myxomas and clot on the right side of the heart. So, you do the CTA, you have them take another breath, and then you do a low-dose scan, which is 1 mSv of exposure, and you get equal enhancement of the right and left side.

MICHAEL POON, MD: I have a question about the temporal resolution of the CT for the evaluation of regional wall-motion abnormalities, particularly in the case of right ventricular dysplasia. From your experience, do you think the CT temporal resolution is fast enough to discern that slight wall-motion abnormality that often appears in left ventricular or arrhythmogenic right ventricular dysplasia (ARVD)?

WHITE: I don’t have any data to prove it, but usually when you’re thinking of making an ejection fraction determination, you want to be ≤100 msec. That’s what nuclear cardiology has shown for years. But this is not the key issue. We’re not focused on an RV ejection fraction. However, let’s say the patient has a pacemaker, the RV ejection fraction would probably be good enough if we couldn’t do the MR. So, really, I’m just making a qualitative determination that a wall doesn’t contract, and I think it’s good enough to do that.

ACHE N BAC H: You also had an interesting case and observations about myocardial bridging. That is something that we see extremely frequently in CT imaging, now much more frequently than we did on the invasive angiogram. We see it especially in the proximal LAD; in fact, we’ll see some extent of bridging in roughly 25% of all cases. Do we have to report that?
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POON: I think that’s a very interesting point. The question is, do you see physiologic squeezing even though anatomically or structurally it appeared to be within the myocardium? If you look at the systolic phase, I always go between the systolic and diastolic phase to see if there’s really any squeezing of the vessel. If you don’t see it, it’s not significant. I guess that may be an important point to report.

ACHENBACH: That’s a good way of going about it, because otherwise we’re definitely overreporting.

POON: You see so many bridges, but if it has no physiological consequence, then I think it’s unimportant.

FISHMAN: I have a technical question. In a lot of your images, you showed 4-dimensional reconstructions. Are you doing those routinely in these types of patients?

WHITE: No. I completely agree with Dr. Achenbach that those images are really more for an audience—your audience may be your cardiac surgeon. The images you need to make the diagnosis and those you need to convey the idea are often two different things. No, I don’t think they are essential; really, ≥90% of diagnoses are found in multiplanar reconstructions and thin MIPs.

POON: Rick, have you tried the coronary CTA with gadolinium? If so, does it look OK?

WHITE: Yes. We use it because we can’t do anything else. It looks pretty good. We’ve had patients who have had iodine allergies, and it’s OK. The coronaries look a little bit anemic, but it’s usually good enough to answer key questions. The clinical services are accepting of that.

ACHENBACH: Do you change your kV setting on it since gadolinium has a different absorption spectrum?

WHITE: That’s a good question. No, actually we haven’t; I have sort of overlooked that. But I think we’re going to be more attuned to doing that with some of the new systems coming out on which we’ll be entertaining different energies.

ACHENBACH: As far as I know, the absorption maximum is in lower kV values for gadolinium, so you have to switch to something like 90 kV. But, I’m not a radiologist.

WHITE: Right, but then your calcium is going to be a problem. It’s a very good question. But you’re going to be robbing Peter to pay Paul. I think. Your calcium is going to be an issue.

MARILYN J. SIEGEL, MD: It also varies with patient size.

FISHMAN: How do you handle contrast timing with gadolinium in terms of volume? Do you do a test bolus?

WHITE: We do it with wishful thinking and just experience—when do we think it’s going to hit? You have a maximum of 60 mL to work with.

JILL E. JACOBS, MD: You showed some cases in which you did both CT and MR on patients. One of the things we’ve realized is an issue of patient throughput. We’re always under a lot of time pressure, as you are, especially on the MR side, since studies can take a very long time. We’re now looking at CT as an initial tool to help tailor an MRI examination. I think it’s very useful to get information initially on CT, to reduce the time you spend doing the MRI.

WHITE: Right, exactly. I didn’t want to steal from Dr. Siegel’s presentation, but I think adult congenital imaging is a prime example, since you don’t know what you’re dealing with and you can get oriented very quickly with the CT. Then you know where you have to add with the MR. Absolutely.

JACOBS: Right. Also, we’ve sort of been pooh-poohing volume-rendering techniques a little bit. But, in addition to it being a useful tool for the clinicians, I find it very useful when you’re looking at anatomic abnormalities for coronary anomalies and for bypass grafts, when it’s sometimes a little bit harder to see the course of a vessel. So I think they are often really useful in evaluating anatomic position.

SIEGEL: I think the volume-rendering techniques are essential for evaluating extracardiac anatomy. The volume-rendering techniques have a more limited role in evaluating intracardiac defects, but it depends on the lesion. For septal defects, axial views usually suffice. For evaluation of pulmonic or aortic stenosis, the volume-rendering techniques may add information about vessel caliber.

With regard to the use of CT and/or MR, do you think that we can start to replace MR with CT in certain areas, such as the evaluation of cardiac masses or pericardial disease?

WHITE: Yes, I think so. I’ve seen a change in my emphasis in the last year. We are seeing more dependency on just CT as it steps up to the plate with function. Although, recall at the case of fibroma—it’s awfully powerful to see that lighting up and well defined on delayed-enhancement MRI. I think we will see MR being pushed more and more to being a specialty item where you deliver just one aspect, and it becomes a very short examination. For instance, for what the MR gave to the fibroma case, you could inject the patient as they’re walking to the MR scanner and just do the delayed-enhancement imaging, and it could be a 10-minute examination.

SIEGEL: Are you referring patients directly for CT? If you are asked, “I have somebody with an echo that shows a cardiac mass. What study should I do next?” Would you suggest MR or CT?

WHITE: At least at my institution, the way we interact allows us to be able to advise and direct things. We’re really approached more and more as consultants, and that’s all the better when we see different groups working together. Then, being a consultant, we can advise how to begin and see the patient through to the diagnosis.

SIEGEL: We have been a consultant in many areas of radiology, and we need to take on this role in cardiac imaging. We now encounter many cardiac lesions, such as pericardial diseases and coronary calcifications, incidentally in the emergency departments. We need to recognize these abnormalities and advise the consulting physician what imaging examination, if any, needs to be performed next.

CARR: I think what’s going to become increasingly obvious, as we deploy these
newer CT scanners with the faster gantry speeds, is that you’re really stopping cardiac motion. In one of my lectures, I pull up some CT scans from the 1980s and early 1990s. In many ways, we had a blind spot there in the mediastinum where the heart is. I think we need to force thoracic radiologists to look at the heart now, because you will see vegetations, clots, and valvular anomalies.

Again, identifying some of the very nicely shown aortic stenosis cases, you can see those on PE studies. In the past 6 months, we’ve picked up 3 people with aortic stenosis on our PE studies just because we were paying attention to calcification as we went through the aortic valve. Again, in trying to do something that will really help people, if you pay attention to the heart, there are several conditions that you can pick up on routine chest CTAs, but they can really change the whole workup of the patient.