Contrast Use in CTA Applications

Coronary CT angiography: A cardiologist’s perspective

Coronary CT angiography can determine whether an intermediate-risk patient should undergo cardiac catheterization and has the potential to assess the quantity and composition of arterial plaque, thereby guiding coronary interventions.

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At the University of Erlangen-Nürnberg, cardiologists have long performed cardiac computed tomographic (CT) imaging, for both research and clinical applications. This article will focus on CT angiography (CTA) of the coronary arteries, offering a cardiologist’s perspective on the most important aspects of image acquisition and evaluation, the comparative accuracy of coronary CTA and invasive angiography, and the types of clinical questions cardiologists can reasonably expect to answer with coronary CTA.

Image acquisition

Patient preparation plays a key role in the acquisition of high-quality data. There are 2 very important steps in patient preparation. The first is administration of nitrates immediately before the patient table is advanced into the scanner. Premedication with nitrates dilates the coronary arteries and markedly improves image quality.

The other critical step is a reduction in the patient’s heart rate to ≤60 bpm, even when using scanners with very high temporal resolution. At our hospital, every patient whose heart rate exceeds 60 bpm receives a beta-blocker. Usually, we administer a single 100-mg oral dose of atenolol 1 hour before the scan. If the patient still has a heart rate >60 bpm after entering the scanner, we check the heart rate again during inspiration, a maneuver that usually causes the heart to slow a little. If the heart rate remains >60 bpm, we administer an intravenous beta-blocker, generally metoprolol in 5-mg doses, up to a total of 4 doses. A combination of 100 mg of oral atenolol, plus up to 20 mg of intravenous metoprolol is usually effective in reducing the heart rate to ≤60 bpm.

We are aggressive about lowering the heart rate for 2 reasons. The first is that it improves image quality. Lengthening the diastolic phase, a time of very little cardiac motion, lessens the likelihood of motion artifact in the CTA images. The second reason is that electrocardiographically (ECG) correlated current-modulation algorithms are much more effective at low heart rates, enabling us to reduce the radiation dose to the patient.

The actual scan sequence takes approximately 5 minutes to perform. The first step is to localize the position of the heart exactly by doing an overview topogram or scout images. Next we gauge the contrast agent transit time in order to determine the timing of image acquisition. There are 2 ways to do this, either by performing a separate test bolus injection and measuring the time it takes the bolus to arrive in the heart, or by using bolus-tracking techniques that automatically start the volume acquisition when contrast material arrives in the heart.

At the University of Erlangen-Nürnberg, we strongly prefer the test-bolus approach. We administer 10 mL of contrast medium, followed by a 50-mL saline flush. The test-bolus technique offers a number of advantages. It serves as verification that image acquisition is set to begin at the optimal level of the heart. It verifies that the intravenous line is placed correctly. It also permits us to give a longer, more complete breath-hold command. We typically say, “Breathe in, breathe out, breathe in, hold your breath.” This 10-second breath-hold command, which is only possible with a separate test-bolus injection, is very comfortable for the patient and results in a reproducible breath-hold.

A separate test-bolus injection also reduces the total contrast volume. The test bolus itself consists of only 10 mL of contrast medium. With bolus tracking, once contrast medium arrives in the heart, the patient takes a breath and the scanner ramps up. During that 4 or 5 seconds, contrast material is being wasted.

Once we have completed the test bolus, we inject contrast material for the duration of the scan, at 5 mL/sec. If the scan duration is 10 seconds, we inject 50 mL of contrast material. If the heart is larger and the scan takes 12 seconds, we...
in longer segments. They are also very useful when evaluating areas of calcification. In Figure 1, axial images show a large amount of calcium in the proximal left anterior descending coronary artery (LAD). A longitudinal reconstruction of the LAD shows that calcium is limited to the bottom of the vessel, with good contrast-enhancement in the lumen above it, a finding that rules out significant stenosis. A cross-sectional reconstruction shows calcification in the wall of the LAD, but no significant obstruction of the lumen.

Maximum-intensity projections (MIPs) are also useful for seeing vessels over long stretches. It is difficult to follow the coronary arteries in a single planar image, as they move up and down and twist in 3 dimensions, often leaving the imaging plane. To see longer segments of the vessels, it is useful to project thicker sections. By layering approximately 5 mm of data, one slice on top of another, it is easier to follow the continuity of the vessel.

Maximum-intensity projections are particularly helpful when the course of the vessel is parallel to the imaging plane. In Figure 2, a 5-mm-thick MIP nicely demonstrates a tight lesion in the proximal LAD, confirmed on invasive angiography.

One disadvantage of MIPs is overlap. For example, the left circumflex coronary artery may be obscured by the left atrial appendage because of overlapping data, making it impossible to evaluate the vessel and perhaps resulting in a false-negative finding.

Three-dimensional (3D) reconstructions are useful for conveying information to referring physicians and patients but are not particularly useful for diagnosis. Figure 3 shows stenosis of the right coronary artery (RCA). Seen very clearly on the 2-dimensional (2D) display, it can also be visualized on the 3D reconstruction. However, the volume rendering does not add any significant information to that already available from the 2D image. Equally important, 3D reconstructions are very subjective. Simply by changing the parameters of the volume-rendering technique, it is possible to make the stenosis disappear and reappear.

Therefore, we strongly prefer 2D methods to prerendered 3D methods or prerendered curved MPRs. For an accurate diagnosis, it is essential that the operator navigate through the data set, looking at every segment of the coronary arteries from a variety of angles.

CT versus invasive angiography

In 2000, the introduction of 4-slice CT scanners enabled high-quality imaging of coronary artery lesions in selected cases. With the introduction of 16-slice scanners several years later, nearly isotropic spatial resolution made it possible to visualize even very short, tight stenoses that would have been missed at a lower resolution. The next-generation 16-slice CT scanners offered faster gantry rotation (370 msec) and a stronger X-ray tube (up to 950 mAs).

Figure 4 shows a multiplanar reconstruction of the right coronary artery. Although the artery has a very curved course, on the MPR, it is stretched out in a single image and reveals a lesion in the proximal RCA that is both calcified and noncalcified. The corresponding invasive angiogram confirms the lesion. It also underscores the tendency of CT to overestimate the degree of stenosis. Coronary stenoses tend to look a little more severe on CT than on invasive angiography, probably as a result of partial-volume effects.

Sixty-four-slice CT has further improved image quality, as well as the predictability of obtaining first-class image quality.

There is a large and growing body of literature comparing CTA to invasive angiography for the detection of coronary stenosis. In 2001, there were just a handful of reports. The number has risen sharply since then; however, it is very difficult to compare individual studies because technology differs from one study to another. Clearly, the results of a study performed using a 4-slice CT scanner cannot be compared with the results of a study performed using a 16- or 64-slice CT scanner.

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Table 1. University of Erlangen–Nürnberg: Protocol for coronary CT angiography

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<thead>
<tr>
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<tr>
<td>Scan duration</td>
<td>~10–14 seconds</td>
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<tr>
<td>Scan range</td>
<td>~130 mm</td>
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<tr>
<td>kV</td>
<td>120</td>
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<td>mAs</td>
<td>850</td>
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<tr>
<td>Detector collimation</td>
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<tr>
<td>Slice thickness</td>
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<tr>
<td>Reconstruction interval</td>
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<td>Table feed</td>
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<tr>
<td>Gantry rotation time</td>
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<tr>
<td>Contrast volume</td>
<td>50–70 mL</td>
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<td>Contrast rate</td>
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We inject 60 mL of contrast material. We begin data acquisition according to the contrast agent transit time, as determined by the test bolus.

We have not observed substantial differences in image quality with various types of contrast agents. The goal is to maximize enhancement of the coronary arteries, but in our experience, use of contrast media with a concentration of 350, 370, or 400 mgI/mL makes little difference in image quality.

Specific scan parameters vary from scanner to scanner. Regardless of the technology, it is critical to use maximum temporal resolution and maximum spatial resolution in order to visualize the small structures of the heart (Table 1).

Once the scan is complete, we evaluate the volume data set at the workstation, maneuvering through it and examining all of the coronary arteries in an interactive way. We create both multiplanar and axial reconstructions, but we rely most heavily on the axial images. Axial images enable us to see the origin of each of the coronary arteries and follow the vessels in cross-section through the data set, observing changes in enhancement.

With a tight stenosis, for example, it is typical to observe good contrast enhancement proximal to the lesion, then an absence of contrast enhancement at the point of stenosis, followed by the reappearance of contrast enhancement in the lumen distal to the stenosis.

Multiplanar reconstructions (MPRs) enable us to view the coronary arteries from a variety of angles. Equally important, 3D reconstructions do not add any significant information to that already available from the 2D image. Equally important, 3D reconstructions are very subjective. Simply by changing the parameters of the volume-rendering technique, it is possible to make the stenosis disappear and reappear.
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**FIGURE 1.** (A) An axial image shows a large amount of calcium in the proximal left anterior descending coronary artery (LAD). (B) A longitudinal reconstruction of the LAD shows that calcium is limited to the bottom of the vessel, with good contrast enhancement in the lumen above it, a finding that rules out significant stenosis. (C) A cross-sectional reconstruction shows calcification in the wall of the LAD, but no significant obstruction of the lumen.

**FIGURE 2.** (A) A 5-mm-thick maximum-intensity projection reveals a tight lesion in the proximal left anterior descending coronary artery. (B) This finding was confirmed on invasive angiography.
There are more subtle but equally important differences among studies as well. Some define a critical stenosis as ≥50% reduction in luminal diameter and others set the cutoff at ≥70% reduction in luminal diameter. In addition, one study might include every coronary segment in the analysis, even tiny diagonal branches, and another study might limit the analysis to the relevant arteries and their proximal segments, mid-segments, and large side branches. Finally, a very important difference between studies is the prevalence of disease in the study population, a characteristic that strongly influences both positive and negative predictive values.

Table 2 lists 4 studies published in 2005,\textsuperscript{1-4} all of which were performed using 16-slice CT in consecutive patients referred for invasive diagnostic coronary angiography. The sensitivity observed in

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<td>Kuettner\textsuperscript{2}</td>
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<td>Hoffmann\textsuperscript{3}</td>
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NPV = negative-predictive value

Although 3-dimensional reconstructions are most useful for conveying information to referring physicians and patients, they are not essential to diagnosis. (A) This volume-rendered image shows stenosis of the right coronary artery, but does not add significant additional information to that already available from (B) the 2-dimensional image.

(A) This multiplanar reconstruction reveals a lesion in the proximal right coronary artery that is both calcified and noncalcified. (B) The corresponding invasive angiogram confirms the lesion. It also underscores the tendency of CT to overestimate the degree of stenosis, probably because of partial-volume effects.
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These studies for the detection of coronary stenosis was 85% to 95%. Ninety-five percent is an exceptionally high sensitivity for the detection of stenosis by a noninvasive technique. By comparison, stress testing, including stress electrocardiography, echocardiography, and perfusion imaging, have a sensitivity of 68% to 88% for stenosis detection.

The studies differ slightly in the types of coronary segments included in the analysis. In general, the analysis is limited to coronary segments with a sufficiently large diameter to permit treatment by catheter intervention (>1.5 mm or >2.0 mm). As expected, the study by Kuettner et al., which included even very distal coronary segments in the analysis, reported a lower sensitivity than the other studies. It is more difficult to assess lesions in the small posterior descending coronary arteries than in the mid- or proximal LAD. Specificity was also high (95% to 98%), and the number of coronary segments that could not be evaluated was low (5% to 7%).

These studies were performed by very experienced operators who took great care in patient preparation, thereby ensuring optimal image quality. Notably, all of the studies reported a very high negative predictive value (96% to 99%). Therefore, assuming good image quality, we can say with a high degree of certainty that the absence of a coronary lesion on CTA means that the patient does not have a coronary artery stenosis. A high negative predictive value is perhaps the most important feature of coronary CTA.

Studies of coronary CTA using 64-slice CT scanners are beginning to appear in the scientific literature. Three studies published to date have reported a sensitivity of 80% to 94% for the detection of coronary stenosis, and additional studies are under way. The study by Leber et al., which reported the lowest sensitivity, enrolled a patient group with a high prevalence of disease. In addition, investigators evaluated all coronary segments, even very small ones. After exclusion of severely calcified segments, their reported sensitivity rose to 87%.

Intermediate-risk patients

Coronary CTA is not expected to replace invasive diagnostic angiography. CT angiography has a number of

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**FIGURE 5.** A 45-year-old man with atypical chest pain, normal resting and stress echocardiograms, and a 45% pretest likelihood of disease. (A) Noninvasive CT angiography revealed a tight stenosis in the proximal left anterior descending coronary artery. (B) A volume-rendered image produced from the data set. (C) The stenosis was confirmed by invasive angiography. The patient was treated with coronary intervention.

**FIGURE 6.** Sixty-four-slice CT scanners have made substantial improvements in visualization inside the stent lumen, at least with certain sizes and types of stents. These images depict: (A) three stents implanted in coronary grafts and (B) a stent implanted in the proximal left anterior descending coronary artery.
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limitations. Its temporal and spatial resolution are lower than those of invasive angiography. Calcification limits the ability of CT to evaluate the coronary arteries. (This problem is lessened, but not eliminated, by improvements in spatial resolution with 64-slice scanners.) Cardiac motion, especially at high heart rates, also limits the ability of CTA to evaluate the coronary arteries.

These technical problems will be overcome in time; however, there are conceptual limitations as well. Coronary CTA necessitates the use of contrast material and exposes the patient to a substantial amount of radiation. The patient must be in sinus rhythm, a requirement that precludes CT examination in some patients. The study provides anatomic information but does not assess the hemodynamic impact of a coronary lesion or provide information on myocardial perfusion. And it is a purely diagnostic test.

For many of these reasons, coronary CTA is not appropriate for patients with a high likelihood of disease. If we expect to discover a critical stenosis, noninvasive imaging does not add useful information. It is better to send the patient directly to the cardiac catheterization

FIGURE 7. (A) Conventional angiography shows a patient with a tight reduction in the lumen of the proximal left anterior descending coronary artery (arrow). (B) Intravascular ultrasound at the same site shows a large amount of coronary atherosclerotic plaque, which is not visible on invasive angiography. (C) Coronary CT angiography shows both the arterial lumen (long arrow) and the presence of noncalcified and calcified plaque (short arrow). (D) A cross-sectional rendering closely resembles the images acquired with intravascular ultrasound. (Images reprinted with permission of the American College of Cardiology Foundation from: Achenbach S, Daniel WG. Computed tomography of the coronary arteries: More than meets the (angiographic) eye. J Am Coll Cardiol. 2005;46:155-157. Copyright 2005 American College of Cardiology Foundation.)
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laboratory for invasive angiography and coronary intervention.

Conversely, the use of coronary CTA for screening asymptomatic individuals does not make sense clinically. Discovery of a peripheral stenosis will not benefit the patient, as treating such a stenosis in an asymptomatic individual does not improve life expectancy.

The most appropriate application of coronary CTA is in the evaluation of symptomatic patients at intermediate risk for coronary artery disease. In such patients, its high negative predictive value enables CTA to reliably rule out coronary stenosis, thereby determining whether the patient requires invasive angiography.

The pretest likelihood of coronary stenosis is highly variable and depends on the age and sex of the patient, and on the type of chest pain. According to a 2002 consensus statement of the American College of Cardiology and the American Heart Association, a 65-year-old man with typical angina has a 94% chance of having at least 1 critical stenosis, whereas a 45-year-old woman with atypical angina has a 22% chance, and a 30-year-old woman with atypical angina has a 12% chance. The cardiologist may also take into account the results of stress testing in gauging the pretest likelihood of disease.

Some patients clearly do not need cardiac catheterization, and others clearly do. Many patients fall in between the two extremes, however. In a patient with a 30% to 70% pretest likelihood of disease, it can be very difficult for the cardiologist to determine whether the patient should undergo invasive angiography. It is in just such patients—that is, those at intermediate risk—that coronary CTA is most helpful.

Figure 5 shows a 45-year-old man with atypical chest pain, normal resting and stress ECGs, and a 45% pretest likelihood of disease. Noninvasive CTA reveals a tight stenosis in the proximal LAD. The patient underwent invasive angiography and was treated with coronary intervention.

Other clinical applications

Coronary anomalies can be easily evaluated by CTA. CT angiography can also reliably visualize occlusion and stenosis in coronary artery bypass grafts. Several publications have reported a sensitivity of 100% for CT angiographic detection of bypass graft occlusion and a sensitivity of 60% to 96% for detection of bypass graft stenosis.

Clinically, however, examining only the bypass grafts in a symptomatic patient is not sufficient. It is important to examine both the native vessels distal to the bypass stenosis and the arteries that did not undergo bypass grafting. We do not yet have enough data to determine whether CTA can reliably assess both bypass grafts and native coronary arteries. We are, therefore, reluctant to use CTA to examine patients who present with chest pain after bypass surgery.

The assessment of coronary stents by CT is quite difficult, and the results are variable. Whether the inside of the stent can be visualized depends on many factors, including scanner technology, the size of the stent, and, most important, the type of stent. We are hopeful that 64-slice CT will enable visualization inside the stent lumen, at least with certain sizes and types of stents (Figure 6).

Another potential future application of coronary CTA would be in the evaluation of atherosclerotic plaque, the rupture of which is responsible for most cardiovascular events. Invasive angiography, although the gold standard for visualization of the coronary lumen, is heavily criticized for its inability to visualize atherosclerotic plaque. Figure 7 shows a patient with a tight reduction in the lumen of the proximal LAD on conventional angiography. Intravascular ultrasound at the same site shows a large amount of atherosclerotic plaque, which is not visible on invasive angiography.

Coronary CTA shows both the arterial lumen and the presence of noncalcified and calcified plaque. A cross-sectional rendering looks very much like the images acquired with intravascular ultrasound.

The ability to visualize atherosclerotic plaque suggests another potential role of coronary CTA in clinical practice. Consider, for example, a patient who is found to have a 40% or 50% stenosis of the proximal LAD on invasive angiography. Although the lesion does not appear to be severe, coronary CTA has the potential to assess whether the plaque is vulnerable to rupture and to aid in determining if the patient needs treatment to prevent future cardiac events. Similarly, coronary CTA has the potential to identify a patient with a heavy plaque burden who might benefit from intensive risk modification.

Coronary CTA also has a potential role in providing information about a coronary lesion before interventional therapy, enabling the interventional cardiologist to determine the best type of stent to use and develop a strategy for achieving optimal stent placement. Coronary CTA can provide information about the presence and anatomy of a stenosis, the amount of calcium present, plaque density and composition, and the extent of arterial remodeling. CT angiography can also assess lesion geometry and the angulation of a bifurcation lesion, information that is difficult to obtain with invasive angiography.

Coronary CTA offers important pre-intervention information on chronic total occlusions as well. A study by Mollet et al examined the ability of coronary CTA to predict the outcome of percutaneous recanalization of chronic total occlusions. CT angiography was better than invasive angiography at predicting procedural success.

Conclusion

CT angiography is an increasingly impressive imaging tool. It offers very rapid and straightforward image acquisition and yields high image quality, in study after study. It also has a high negative predictive value and is, therefore, a reliable tool for ruling out coronary stenosis.

Coronary CTA has the potential to answer key questions cardiologists face every day: Does a patient, particularly one at intermediate risk for coronary artery disease, need cardiac catheterization? Is a mild-to-moderate lesion on invasive angiography actually composed of vulnerable plaque and in need of intervention to prevent plaque rupture?
Does a patient have a heavy overall plaque burden and, therefore, need intensive risk modification? And, what is the best strategy for performing a coronary intervention, particularly on a bifurcation lesion?

Potential future applications include bypass graft assessment, stent imaging, plaque imaging, and preinterventional treatment planning.

References

Discussion

ELLIOT K. FISHMAN, MD:
Thanks, Stephan. Let’s open the floor to questions.

Marilyn J. Siegel, MD:
I have some questions concerning the optimal heart rate for performing CTA of the coronary arteries. You discussed methods to lower the heart rate. Is there a rate at which you will not do the scan?

Stephan Achenbach, MD:
No. I wouldn’t do that. If I really want information and I believe that CT might be useful for the patient, I would scan a patient even if I cannot bring down his/her heart rate. It’s not that success critically depends on the heart rate being low; it’s just that the success rate is higher if the heart rate is low. But even with higher heart rates, even 70 to 90 beats per minute, using multisegment reconstruction technology and so on, you can still get very good quality images in many cases. It’s just that the success rate will be higher if the heart rate is lower. Also, the considerations about radiation exposure make us lean toward lower heart rates, of course.

Siegel: We found the same results in infants and children, who (as you might expect) often have higher heart rates. You can get high-quality images in most of these patients even with their higher heart rates. However, the studies in this patient population are not dedicated coronary artery studies but are usually performed to evaluate congenital heart disease. The higher heart rates do not appear to be a detriment in evaluating congenital lesions.

You also talked about the dose modulation technique, and dose is obviously a big issue. So given that, what is your average mAs setting? What dose do you think you need for an optimal study?

Achenbach: In fact, we find that image quality is so crucially important to evaluate the data set, so we usually tend to use very high mAs. Basically, unless it’s a very, very skinny patient, we use just about as much as the scanner will give us. Instead of using the mAs to reduce the dose, we’d rather use tube current modulation to reduce the radiation exposure to the patient. So, again, it depends on the type of scanner you have available, but usually you would use pretty much what the scanner can give you, as far as tube current is available.

Fishman: You mentioned that you always use nitrates in all patients. Could you explain to us your thoughts on the subject?

Achenbach: You have to think, what are the potential downsides of nitrates? Nitrates will never make your images worse. Dilating the coronary arteries will improve the visualization. In fact, in most cath labs, nitrates are given either in a systemic form or directly into the coronary arteries to improve the assessment of coronary stenosis. So, we are trying to simulate these situations in the cath lab. I would heavily recommend using nitrates for that reason. The potential reasons not to use them are again twofold. Some physicians have concerns that giving nitrates might increase the heart rate and then decrease image quality. But we don’t see that effect, especially in patients who have received beta-blockers. If you give nitrates, the heart rate does not go up measurably during the scan.

There are also worries that the patient might have a drop in blood pressure and might have difficulty in making it through the scan clinically. But we use nitrates so frequently and we never have any problems. Of course, you should not give it to some patients—patients who have an aortic stenosis should not receive nitrates, nor should patients who have outflow tract obstruction. Those are the general contraindications, but, other than that, we don’t see any problem with nitrates. It’s rapid, it’s cheap, and it makes your images look so much better that, in almost all cases, you should use them.
**FISHMAN:** When do you give it, specifically? What dose do you use?

**ACHENBACH:** We put the patient on the table, we prepare the patient, we attach the EKG leads, explain to the patient what to expect, we give additional beta-blockers if necessary, and then the last thing we do before we advance the patient table into the scanner is to give the nitrates. Then the scan starts. Since we do overview images and then test bolus, it is probably roughly 2 minutes before the actual scan starts, and that’s the onset of the effect of nitrates—in just 1 or 2 minutes.

We give 0.4 mg of isosorbide trinitrate, just the usual dose. We use a spray, but you can use capsules, whatever is available.

**MICHAEL POON, MD:** Some centers like to use the spray. I have seen many patients in whom the pills sit in their mouths and do not dissolve if they don’t have enough saliva. Sometimes, the pill is still in the patient’s mouth after the scan. So, the spray is more consistent. It’s easier to just open the mouth and spray it in.

**FISHMAN:** One issue we had with the spray, and other institutions may have this also, is the trouble getting medications approved when it is a reusable product. Often, as in our situation, it became an issue. They don’t want anything that’s reused.

**RICHARD D. WHITE, MD:** Would you think that the preoccupation with pursuing the stenotic lesion, and using that as a measure of success of this technology, is drawing the attention away from the development of other useful things you commented on? It seems to me to be a double-edged sword. Ultimately, you may not want to end up where the industry is going. Does that concern you?

**ACHENBACH:** You point out a very important issue. Cardiologists, in general, have so far focused a lot on the stenotic lesion in the coronary arteries. Only in recent years, really, has there been a shift toward recognizing that treating the stenosis is not the only thing that’s important. Looking at the patient and the risk for future cardiovascular events is at least as important. Right now, as we undergo this paradigm shift, here comes CT angiography, which can show the stenosis but also can show the nonstenotic plaque.

We are currently focusing a lot on CT angiography to detect stenosis, and that might potentially deter us from looking at all the other good things that CT coronary imaging can do. For example, all the calcium discussion that had been going on has almost died down. People are not as interested in coronary calcium anymore. Now, everybody worries about CT angiography to detect stenosis. Of course, we should not forget everything else just because we see stenosis.

But I see something else happening that I might add to that. CT angiography has matured, and now has a quite high negative-predictive value. It can be useful in the context that I have outlined—which is my personal opinion—that we can use it to rule out stenosis in certain patients who would otherwise have to go to catheterization. But I see cardiologists who had been very reluctant to adopt CT angiography. It’s the new thing, and image quality was not always perfect in years back, so they were very reluctant to adopt it. But now they are accepting it and, at the same time, are also sometimes overusing it, using it in patients who don’t need it, and also overinterpreting.

“Oh, this patient doesn’t have a stenosis, but here’s all this plaque, so let’s either send him to angiography or do a very intensive treatment.” That’s the data-free zone that we heard about. There is no data on what to do. We have no firm ground to stand on when we use all the information about noncalcified plaque. Some people call it “soft plaque,” but that is a term that I don’t like very much because we don’t really know whether it’s soft or hard. We just know it doesn’t contain any calcium. So we wander off into an area in which we have no data. We have data about the ability to rule out stenosis and data about the predictive value of coronary calcium. But that’s about all the data that we have, so we have to be aware of that.

**POON:** I think the most challenging question is determining when to call stenosis “significant,” because I think the negative-predictive value is obvious if you do not see any plaque or calcium—anyone can call that. The question is, at which level of stenosis, be it calcified or noncalcified, do you say, “You need to do something.” At this moment, at least from my read of the literature, there does not seem to be any real consensus on what to consider to be clinically significant stenosis on a CT?

**ACHENBACH:** That’s absolutely true. Some use the 50% diameter reduction threshold, others use the 70% diameter reduction threshold. So there is no consensus. But that’s also why I say that the value of CT is rather to rule out stenosis and to say, “This is a stenosis that definitely requires treatment.” That, CT cannot provide.

The decision about whether a stenosis needs treatment or not is very difficult to make by CT; but what we can do and say in many patients is, “This patient doesn’t have any stenosis. This patient does not need to go to cath.” That’s why I always try to shift it, to say we can identify patients who do not need a cath. This is to be used to identify patients in whom we want to avoid cath. So that is a bit of a difference.

**POON:** Let’s say you don’t send the patient to get a catheterization; then, at which level of stenosis do you say a stress test is necessary?

**ACHENBACH:** A stress test should always be performed if you have a suspicion of a coronary stenosis and want to send the patient on to cath. So, in those others, in CT we use the 50% threshold, which gives us the security of not missing any lesions, even though we might identify some patients who may end up not having a high-grade lesion when the catheterization is performed. Then again, you should not do a CT study and then send the patient off to catheterization immediately. A stress test is always part of the workup in the cardiology world.
SIEGEL: One of the important issues in patients with ischemia is ventricular function. Are you looking at functional changes in patients with ischemia? When you’re doing coronary artery studies, do you evaluate left ventricular wall motion? Is that an issue?

ACHENBACH: Are you talking about the myocardium? Yes. There are other things that CT can provide. The CT scan performed to visualize the coronaries can be used to look at left ventricular function. Of course, in some patients you might identify regions with wall-motion abnormalities, which is just another indication that ischemia might be present.

But in patients who come from a cardiology workup, you will usually have an echocardiogram, so you should have the information about wall-motion abnormalities already available. If you want to use wall-motion abnormalities to get information about the hemodynamic significance of a coronary lesion, you would usually have to assess them not at rest, but under stress. So you would have to do a repeat scan with physical or pharmacological stress, and that’s usually not done because of the radiation and the contrast exposure.

So, yes, you can extract a lot of additional information: Left ventricular function, you can sometimes see areas of perfusion deficit, but that’s all at rest. The cardiologist is usually not as interested in that information about what’s going on at rest because we have that from the echo, and stress testing in CT is really not very practical.

SIEGEL: I ask about wall motion because radiologists who will be doing coronary artery CTA will want to know what other information they can get from the scan. Are there other areas they should routinely evaluate?

ACHENBACH: Oh, yes, there are.

SIEGEL: That’s an important point, but, of course, it is at rest.

ACHENBACH: Absolutely.

FISHMAN: It would be very helpful from both the CTA perspective and from the calcium scoring perspective to have some form of template. People always ask, “What’s a good template for reporting?” As you commented on, “What should I be saying in a report beyond it’s negative or it’s positive? How much should you be saying? How much do I need to say? Is there a very logical way for reporting it?” Cardiologists have a pretty much set form when they do cardiac caths. Do you have a set form when you do the cardiac CT?

ACHENBACH: Yes, we do. We want to be very clear about what we find. We try to report our findings, but we always comment on the image quality. That is a very important first step because it gives our referring doctors or my colleagues who read the reports a feeling of how much we can rely on the test. If we say very frankly, “This is a patient with lots of ectopic beads, and the image quality is really bad, but we don’t see any lesion,” we very clearly state in the reporting, in the summary, that we might not be able to absolutely rule out a lesion because image quality wasn’t good enough.

So image quality is part of the report. Cardiac anatomy is part of the report. If you have some anomaly, you will always want to report it. We go segment-by-segment, or artery-by-artery, and we report on the presence of plaque, calcified plaque, and stenosis. So we should always report, even if no stenosis is present, that no stenosis with a significant lumen reduction is present. We should always report on whether or not we see calcium and whether or not we see non-calcified plaque because it’s potentially prognostically important, as Dr. Carr has pointed out.

WHITE: If you stumble on a densely calcified plaque and you can’t see the lumen, what do you say?

ACHENBACH: Exactly that.

WHITE: But do you indicate the likelihood that there could be something there, or do you just simply say, “I can’t tell anything.”

ACHENBACH: Let’s assume there is a densely calcified plaque of the proximal LAD. I write, “Left main is normal. Proximal LAD severely calcified lesion, which prevents assessment of coronary stenosis, and circumflex as well as the right coronary artery are normal.” Then in the summary, I say, “This patient has a severely calcified LAD, and I cannot rule out the presence of stenosis in the proximal LAD.”

POON: I’d just like to add to that based on some of the work we did with the Munich group looking at resting hypoperfusion, which is a first-pass study that you’re doing with CT. Oftentimes, we see an area of hypoperfusion that gives you some indication whether a certain area had clinically significant stenosis. We did a correlation with MR, delayed hyperenhancement, and MR perfusion, and found that to be quite good. So something that I routinely report in my center, in addition to the coronary information, is whether there is resting hypoperfusion in any particular region. I find that useful if I find it, and it gives me some sense of whether there’s significant plaque and obstructive plaque in a certain region.

ACHENBACH: So you should definitely comment on the myocardium—if you have aneurysms, aneurysmal scars, or hypoperfusion that’s obvious. If you have severe hypertrophy, you should report all that. That’s clear.

J. JEFFREY CARR, MD, MSCE: How do you actually measure stenosis? Going back to just the basic operational issues, do you try to pick the cross-section where you’ve got the greatest narrowing and measure diameters?

ACHENBACH: Nobody that I know of does measurements inside the coronary arteries. It is all visual assessment—we have to state that very clearly—the reason being that even though the images that we have displayed in our computer monitor look very smooth and they look like they have very, very high spatial resolution, the true physical spatial resolution is in the 0.5-mm range. If you have a coronary artery that has a 2-mm diameter, and you have 0.5-mm pixel, true physical pixels or voxels, so we have 4 voxels in the coronary artery.

How do you want to make the distinction whether this is a 55% or 57% stenosis? You can’t, even though the
images we see might display something that seems to be of very high resolution because they’re heavily interpolated. So nobody I know who has lots of experience does measurements of stenosis severity; it’s all visual assessment.

**FISHMAN:** You mentioned concentration of contrast. You commented that the higher concentration really does not add a lot to the process.

**ACHENBACH:** That’s not something that we have evaluated scientifically or that I know of studies that have been performed. But our experience, and that of others, in using slightly varying concentrations of contrast is that higher concentration doesn’t make a whole lot of difference. You want good contrast enhancement, but small differences in the contrast concentration injected really don’t make a very noticeable difference. At the initial stages of CTA, I remember that there was some discussion that you do not want too much contrast inside the coronary arteries. There were worries that you might have the same density of contrast and calcium and might not be able to tell those two apart—but that has not proven true.

Currently, the concept is to get as much contrast inside the coronary artery as possible. You can use high flow rates and high-concentration contrast agents, but subtle differences in the contrast concentration are not really noticeable in the scan. There are many experts here around the table, and they might have a different opinion. I’m just stating mine.

**WHITE:** We’ve done the same sort of anecdotal science and have actually preferred 370 mgI/mL to lower concentrations.

**ACHENBACH:** Do you see a difference between 370 and 350 mgI/mL, for example?

**WHITE:** Oh, probably not. But we may see it between 370 and 320 mg I/mL, and certainly 270. We have found 370 to work best across the board using a flow rate of 5 or 6 mL/sec for a coronary. It depends on the condition.

**JILL E. JACOBS, MD:** I think there is one caveat in trying to actually characterize plaque densities and trying to distinguish lipid plaques from fibrous plaques, although not as much in terms of calcified plaques. Studies have shown that the densities you measure are actually dependent on the surrounding concentration of contrast, so you may get varying density measurements with varying levels of contrast in the lumen of the artery surrounding them. That’s one thing that probably needs further study.

**ACHENBACH:** Yes, it needs further study because there is so much uncertainty at the moment about whether or not you can determine plaque characteristics with measurements. Of course, as you correctly pointed out, there is very heavy influence of the contrast enhancement next to the plaque on what you measure inside the plaque.

**FISHMAN:** We’ve tended to use either 350 or 320 mgI/mL isosmolar contrast. Does anyone have any experience with isosmolar agents?

**POON:** We use isosmolar contrast on almost all patients. We found that really the most important factor, in my opinion, is timing. If your timing is right, it really doesn’t matter whether you use isosmolar 320 or 370 mgI/mL. Once you get the high iodine concentration, I think you worry about the effect it has. Plaque analysis becomes difficult because it becomes so bright that it might affect your ability to really look at a plaque. But I think timing is everything. If you time it right, you can get by with a lower iodine concentration.

**CARR:** One of the things that is really important is to have a consistent heart rate over the time that you’re acquiring the data. Stephan and many of us have been working from single-slice CT now up to 64-slice CT. When we started on the 4-slice in small pilot studies, we had a 20-, 30-, or even 40-second acquisition window. Timing was much more critical. What you saw is that when you bolus patients with an osmotic load through a power injector, there is a tendency over time for their heart rate to accelerate. Anecdotally and with some animal data that we have, with isosmolar contrast, individuals maintain a much more consistent heart rate during the 10- to 15-second scan period. I don’t see the acceleration of heart rate after the infusion as frequently. I’ve sometimes seen people whose heart rate started to tick up even on beta-blockers. I don’t know if you’ve seen that.

**ACHENBACH:** You can see it occasionally. Absolutely. But with the shorter breath-hold now, it’s less of an issue.

**FISHMAN:** It’s been published in some of the cardiology literature on cath studies that isosmolar has the advantage that the heart rate doesn’t change when you give the bolus. Another benefit is the fact that some of the side effects, the very minor ones like warmth or slight discomfort, do not exist, for the most part, with isosmolar. Therefore, the patients don’t get quite as anxious, and you just don’t see that change in heart rate when you start injecting.

**POON:** Stephan’s approach, which I use also, is to give that test bolus. It helps a lot in getting the patient ready for what is coming. It is that unpredictable sudden rush of contrast that often gets the patient nervous. Having gone through many, many studies, I think the test bolus and the careful coaching in between scanning really helps the patient to ease the adrenergic surge. That’s why I think test bolus is probably a better approach than bolus tracking.

**ACHENBACH:** It’s a very simple thing, but it’s very, very important to instruct the patient about what to expect during the scan. You want perfect results; even if it’s only a short 5 or 10 seconds, depending on the scanner and the patient, it needs to be a perfect result. So tell the patient that it’s really, really important, and you have to tell the patient that it might feel kind of warm and funny. We have had patients who say to us in the middle of the scan, “I’m feeling something warm. What’s going on?” Then the scan will not be very good. So it’s really important to take your time, and it may take only half a minute, but tell the patient what’s going on.

**CARR:** One of the other things we found as we got to the 64-slice scanner and as our scan times got shorter is that
there is a tendency for the technologist to want to start the scan immediately at the end of the breath-hold. So we worked with our technologists, saying, “Now that we’ve got this new scanner, we want to have a pause so that we’re sure that the person is really holding his breath.” It’s much like what we do with our cardiac MR, where the technologists are actually watching the patients, and then they start. In our prerecorded voice we use for CT, we have an extra couple seconds’ pause, from when we say, “Okay, hold your breath,” whereas in the old days, if you had a 30- or 40-second scan, you really wanted to start right away. If you only have a 15-, 10-, or an 8-second scan, it’s good to have that pause so that the person is really motion-free.

**FISHMAN:** An important thing you mentioned is the technologist aspect of the study. I think we’ll come back to that. That’s a very critical aspect. In our situation, we have more than 20 technologists at Hopkins, but we have 3 or 4 technologists who really do the routine cardiac studies. We have some technologists who are really gung ho, but they raise the patients’ heart rate by 15 beats because they come on there like the Marines. They are very nice, but it’s the wrong patient to say, “Okay, we’re going to do this. We’re going to do this right.” It doesn’t work. So technologist education is a very critical part of making this study successful.