Top 10 indications for coronary CTA

Ruling out stenosis in patients at low-to-intermediate risk for coronary artery disease tops the list, but coronary CT angiography has a much broader role to play.

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The leading indication for coronary computed tomographic angiography (CTA) is in ruling out coronary stenosis in patients with low-to-intermediate risk for coronary artery disease. Coronary CTA has the potential for broader application, however. This article will explore 10 indications for coronary CTA, dividing them into 3 general categories: ruling out coronary stenosis, establishing the patency of bypass grafts, and resolving questions after cardiac catheterization (Table 1).

Crafting a "Top 10" list is, by definition, a subjective exercise. This list, however, is based on scientific data, knowledge of recent advancements in CT technology, and an understanding of the diagnostic needs of clinicians and patients.

State of the art

Thanks to rapid advances in scanner technology, CTA is capable of producing stunning high-resolution images of the coronary arteries. Dual-source CT is the latest major technical innovation, but it was the 64-slice scanner, with a spatial resolution of 0.4 mm and a temporal resolution of 165 msec, that made coronary CTA a practical reality for clinical diagnosis.

As impressive as recent technical achievements are, CTA continues to fall short of the clinical gold standard, invasive coronary angiography. The spatial resolution of invasive angiography is 0.2 mm, twice that of coronary CTA. When considered in 3 dimensions, this seemingly small difference yields an 8-fold difference in spatial resolution.

Invasive coronary angiography has extremely high temporal resolution. While the frame rate is usually between 12 and 30 images per second, the exposure time for a single image frame captured during invasive angiography is approximately 8 msec. This dramatic advantage in temporal resolution as compared with CT highlights an important challenge for CTA in imaging the beating heart.

Coronary CTA and invasive angiography both expose the patient to radiation, and both require the use of iodinated contrast material. They differ in the method of contrast administration, however. Coronary CTA involves intravenous injection of contrast material, whereas invasive coronary angiography benefits from direct injection of undiluted contrast material into the coronary artery. Therefore, the degree of contrast between the vessels and the surrounding structures is substantially higher with invasive coronary angiography.

Additional limitations of coronary CTA include the need for the patient to be in normal sinus rhythm and the inability to proceed directly from diagnosis to intervention.

In addition, heavy calcification may obscure the lumen on coronary CTA, making it difficult to accurately determine the degree of stenosis. This problem is less prominent on a 64-slice CT scanner, however, given its high spatial resolution.

Of these technical differences, temporal resolution remains the most challenging, making CT vulnerable to motion artifacts at high heart rates. Indeed, there is an inverse relationship between heart rate and CT image quality.[1] The higher the heart rate, the greater the likelihood of blurring the coronary arteries.

It is important to note that accurate assessment of calcified coronary arteries by CT angiography depends not just on spatial resolution but also on temporal resolution. As shown in Figure 1, blurring of calcified structures due to cardiac motion accounts for most of the problems encountered in the evaluation of heavily calcified coronary arteries. When motion is suppressed through very high temporal resolution or multiphasic reconstruction, even severely calcified coronary arteries often are evaluable by CT angiography. In Figure 2, dual-source CT—which has a temporal resolution of 83 msec—clearly shows the arterial lumen in a patient with large areas of calcification in the left anterior descending (LAD) coronary artery.

To overcome the limitations of temporal resolution, it has become standard practice to administer beta-blockers to virtually all patients. At our institution, we aim for a heart rate <60 bpm for 64-slice CT, which ensures a predictably high image quality. To further optimize image quality, we administer nitrates immediately prior to the scan, in order to

Table 1. Top 10 indications for coronary CT angiography

Rule out coronary stenoses

1. Chest pain, low-to-intermediate likelihood of disease
2. Preoperative evaluation, non-coronary surgery
3. Intermittent arrhythmias
4. Alternative to invasive angiography if invasive angiography can only be performed at high risk

Establish patency of bypass graft

5. Alternative to invasive angiography
6. Bypass graft not visualized on invasive angiography

Resolve questions after cardiac catheterization

7. Coronary anomalies
8. Native coronary artery not visualized on invasive angiography
9. Clarify findings of invasive angiography
10. Guidance of percutaneous coronary intervention

dilate the coronary arteries. Another key step is the use of high-concentration contrast material (370 mgI/mL) followed by a saline injection. This not only creates a tight bolus of contrast material in the left side of the heart and coronary arteries, but also eliminates artifacts that can result from retention of contrast material in the right side of the heart. Proper training of patients in breath-holding techniques is also important.

Accuracy

Despite its limitations, coronary CTA has certain advantages over invasive angiography, the most obvious being that it is noninvasive. In addition, coronary CTA can be performed quickly, is becoming increasingly available even in medium-sized hospitals, and is less costly than invasive angiography. Equally important, coronary CTA yields images that can be reconstructed in multiple ways and viewed from any angle. Finally, coronary

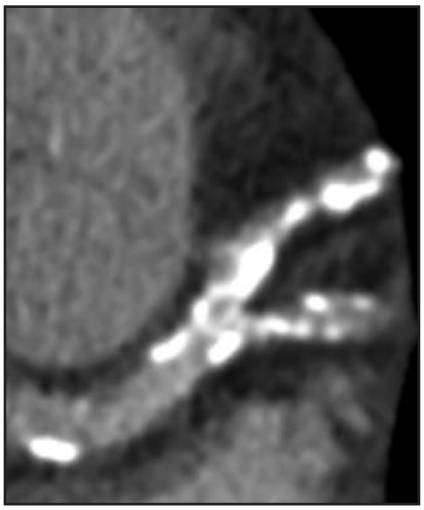

FIGURE 1. *Blurring of calcified structures caused by cardiac motion complicates the evaluation of heavily calcified coronary arteries.*

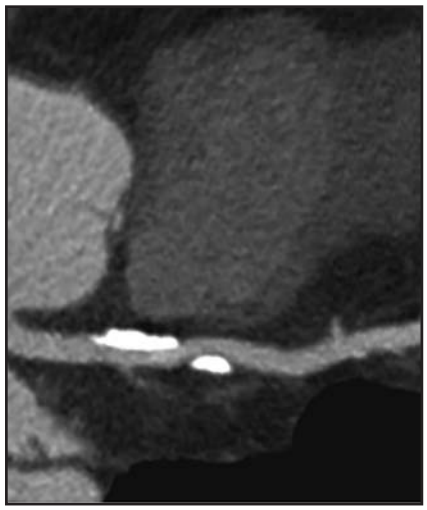

FIGURE 2. *When motion is suppressed through very high temporal resolution, even severely calcified coronary arteries are often evaluable by CT angiography. This image, which was acquired on a dual-source CT, with a temporal resolution of 83 msec, clearly shows the lumen of the left anterior descending coronary artery, despite heavy calcification.*

CTA is proving to be a highly accurate diagnostic tool in selected applications.

Several studies have shown coronary CTA to have a sensitivity of approximately 95% for the detection for coronary artery stenosis and a specificity of >90%—a very high value for a noninvasive imaging technique.[2-4]

However, in gauging the clinical utility of an imaging technique, it is often more relevant to evaluate data in terms of the detection of disease in a given patient rather than in a given coronary artery. Several recent studies have reported the per-patient accuracy of 16- and 64-slice coronary CTA for the detection of at least 1 significant stenosis of the coronary arteries. Sensitivity is impressively high—95% to 100%. Specificity is slightly lower—83% to 100% for 16-slice CT and 90% to 100% for 64-slice CT—largely because of the tendency of CT to overestimate the severity of stenosis, particularly in calcified arteries.

Perhaps more important, the negative predictive value is approximately 95% to 100%. Therefore, if the CT scan is of high quality and does not show coronary artery stenosis, the physician can be very confident that the patient does not have significant coronary artery disease.[5-13]

CT angiography is also highly accurate for the detection of bypass graft patency and occlusion, with accuracies of 100% reported in many studies.[4] The accuracy of CTA for the detection of stenosis in the native coronary arteries in a patient who has undergone bypass surgery is not as well established. It is substantially more difficult to evaluate such patients with CT angiography, as the native coronary arteries tend to be severely calcified and the coronary lumens small.

Rule out coronary stenosis

Taking into account all of the preceding information, it is possible to devise a list of the Top 10 applications of coronary CTA. As mentioned earlier, the most important application is to rule out coronary stenosis in patients with a low-to-intermediate likelihood of coronary artery disease. Figure 3 offers an excellent example. This 56-year-old woman who complained of occasional chest pain and, on bicycle stress electrocardiography (ECG), developed ST-segment changes in the inferior leads. To further clarify her clinical condition, the patient underwent coronary CTA, which indicated normal left main, LAD, left circumflex, and right coronary arteries. Two-dimensional reconstructions were sufficient to convince physicians of the absence of a coronary stenosis. Three-

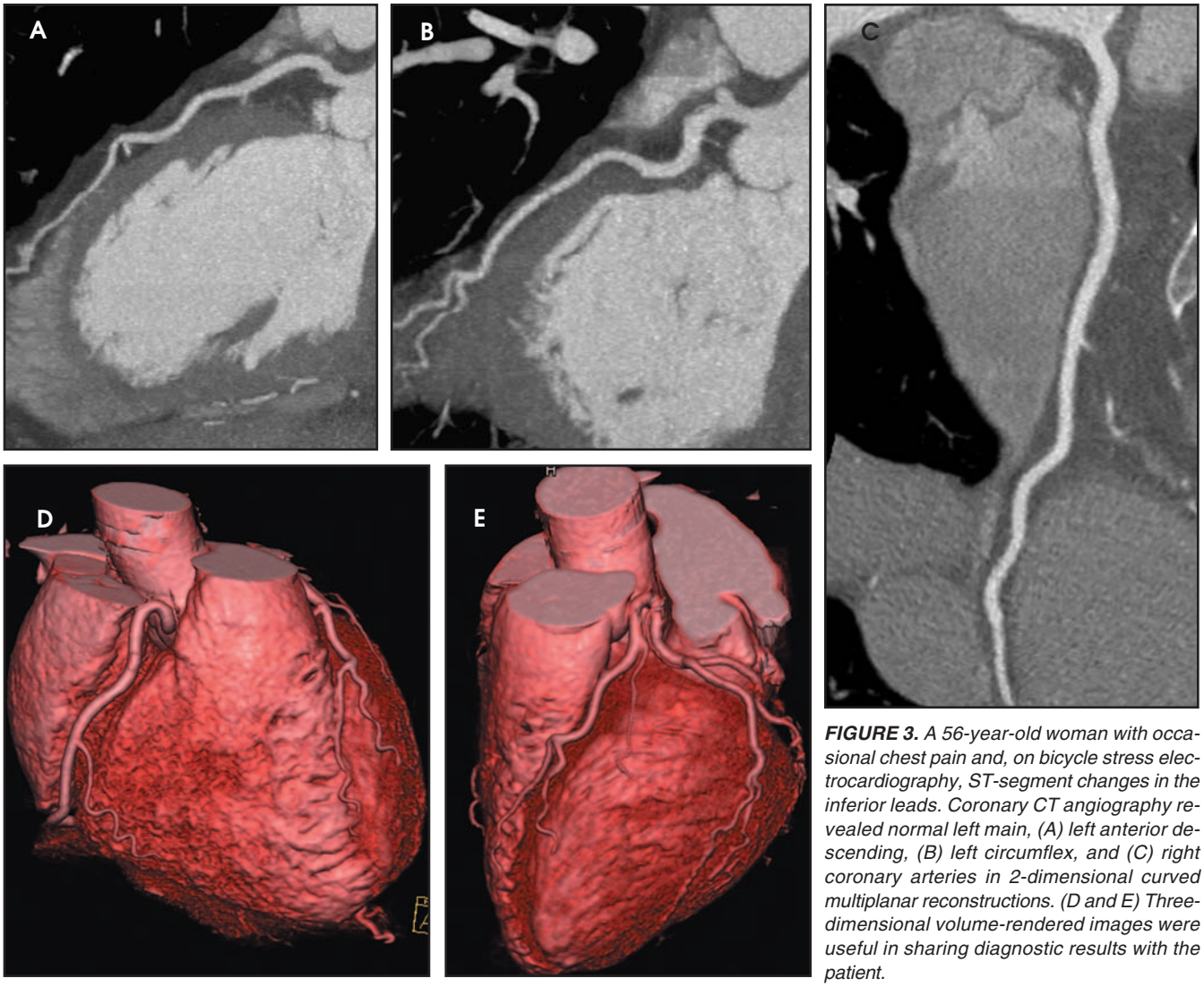

FIGURE 3. *A 56-year-old woman with occasional chest pain and, on bicycle stress electrocardiography, ST-segment changes in the inferior leads. Coronary CT angiography revealed normal left main, (A) left anterior descending, (B) left circumflex, and (C) right coronary arteries in 2-dimensional curved multiplanar reconstructions. (D and E) Three-dimensional volume-rendered images were useful in sharing diagnostic results with the patient.*

dimensional volume-rendered images were used in discussions with the patient.

In such cases, the most important question that coronary CTA can answer is whether the patient needs to undergo cardiac catheterization. If the CT scan is of high quality and does not show coronary stenosis, the physician can reliably say that the patient needs no further testing. For this reason, coronary CTA has enormous potential in the evaluation of patients who come to the emergency room with chest pain, many of whom have a low likelihood of coronary artery disease. There are few data on the accuracy and effectiveness of coronary CTA in the emergency room, but this approach is being evaluated in many medical centers today.[14-16]

In the past, performing a CT scan and an invasive angiogram in immediate succession would likely have raised concerns about the potential for nephrotoxicity, given the large contrast load. Today, coronary CTA involves the use of only approximately 60 mL of contrast material, a volume small enough to minimize such risks.

Another application that comes under the general heading of ruling out coronary stenosis is the evaluation of patients before noncoronary cardiac surgery. An example would be an elderly patient with an atrial myxoma diagnosed on echocardiography. Coronary CTA could be used to evaluate the patient before surgery to remove the myxoma, potentially avoiding the need for invasive angiography.

Coronary CTA is also performed as part of the work-up of intermittent arrhythmias—for example, in a patient with a history of syncope and ventricular tachycardia on Holter monitoring. Often, the electrophysiologist needs to rule out coronary artery disease in such patients. If the arrhythmias are only intermittent, CT is a good option for performing that evaluation.

Occasionally, CTA is indicated for ruling out coronary stenosis in a patient who is unable to undergo invasive angiography or would be at very high risk during the procedure. Figure 4 shows a 53-year-old patient with a large (approximately 10-cm) aneurysm of the aortic root. Although cardiac catheterization could not be performed, coronary CTA visualized the

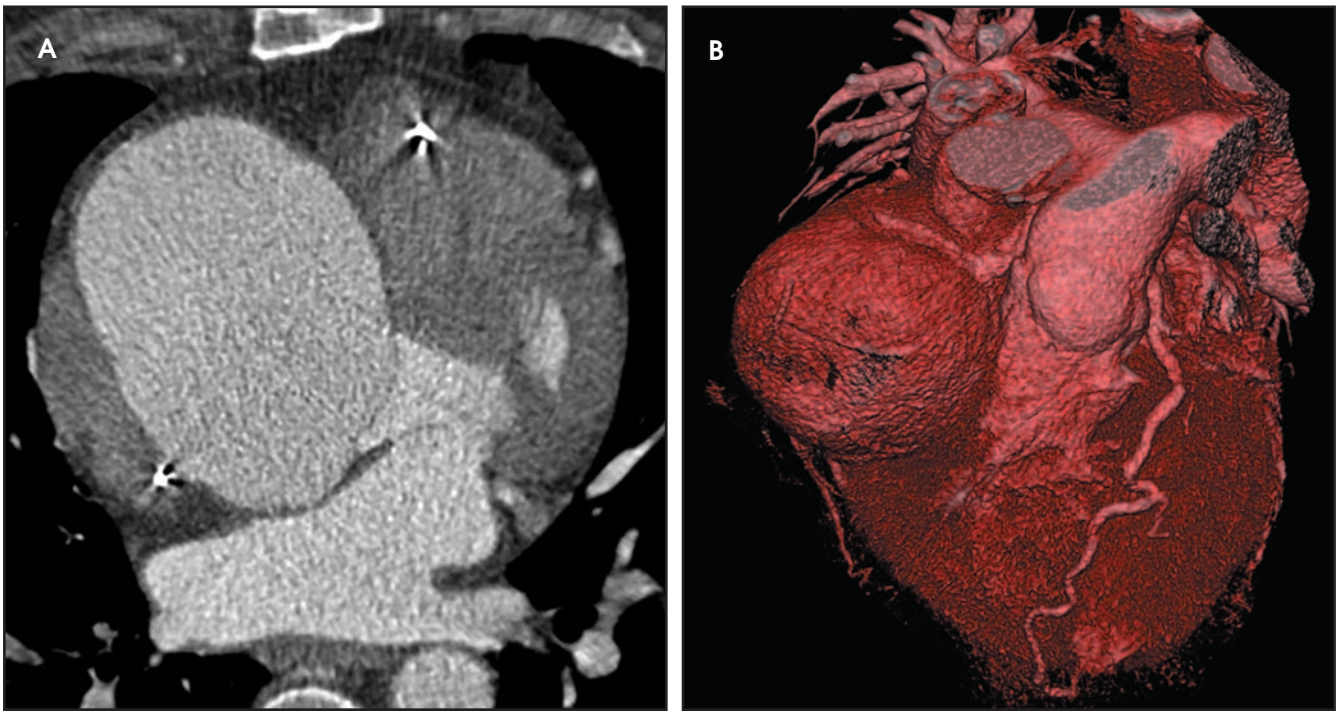

FIGURE 4. *A 53-year-old patient with an approximately 10-cm aneurysm of the aortic root. While cardiac catheterization could not safely be performed, (A and B) coronary CTA visualized the aneurysm and demonstrated normal coronary arteries.*

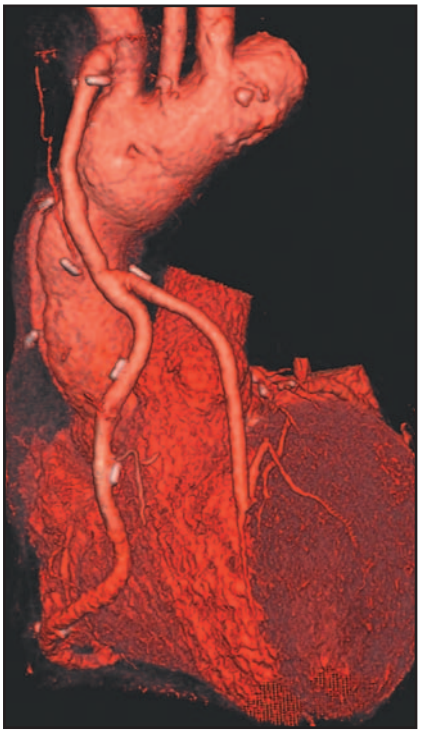

FIGURE 5. *Invasive angiography failed to show a Y-shaped bypass graft to the left anterior descending and right coronary arteries in this patient. CT angiography provides an explanation: The superior anastomosis is to the brachiocephalic trunk, which had not been explored by catheter.*

aneurysm and revealed normal coronary arteries. The patient successfully underwent surgery.

Bypass-graft patency

Coronary CTA is also indicated for establishing bypass-graft patency. It is a less compelling indication than ruling out stenosis of the native coronary arteries, however, because CTA has been shown to be reliable only in the assessment of the bypass graft itself. We do not yet know whether CTA can be used in a complete evaluation of the bypass patient, including the native coronary arteries.

Within the category of establishing bypass-graft patency, one application of coronary CTA—albeit an infrequent one—is as an alternative to cardiac catheterization in high-risk patients. An example might be a patient with Marfan syndrome, a history of aortic dissection, and symptoms that are suggestive of ischemia in the myocardial territory that is served by an aging bypass graft. Without risking cardiac catheterization, CTA can easily establish graft patency or occlusion in such a patient.

Another infrequent but useful application of CTA is determining the patency of a bypass graft not visualized on invasive angiography. Figure 5 shows a patient in whom invasive angiography failed to depict a Y-shaped bypass graft to the LAD and right coronary arteries. CT angiography clearly shows why: The superior anastomosis was not to the ascending aorta, as is usually the case, but instead to the brachiocephalic trunk, which was not explored with the angiographic catheter.

Questions after catheterization

Coronary CTA is occasionally indicated as a way to answer questions that arise during cardiac catheterization. One specific application is clarifying the origin and course of anomalous coronary arteries identified on invasive angiography. To accomplish this task during cardiac catheterization would require multiple image acquisitions from different angulations—and in many cases the anomalous course of the vessel would remain uncertain. It is much easier and more successful to examine anomalous coronary arteries with CTA.

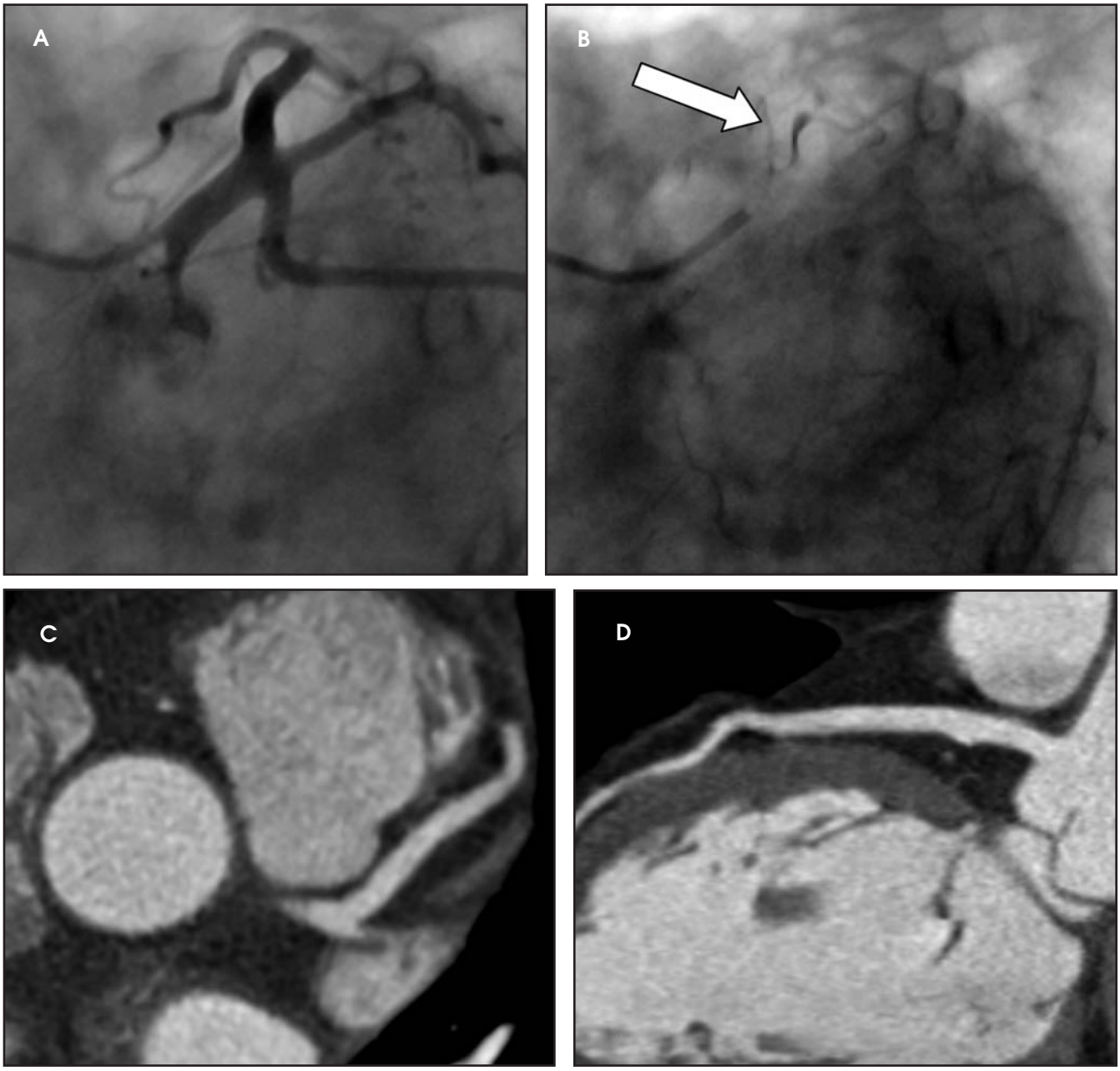

FIGURE 6. *A 54-year-old patient was suspected of having a dissection of the proximal left anterior descending coronary artery, (A and B) which was suggested by the persistence of a small amount of contrast material (arrow) after each injection. (C and D) Coronary CT angiography shows that the proximal left anterior descending coronary artery is completely normal, suggesting that the persistence of contrast material was the result of a flow phenomenon.*

Just as with a bypass graft, native coronary arteries are not always visualized on invasive angiography. For example, a patient with an anterior-wall myocardial infarction might have wall-motion abnormalities on echocardiography, ST-segment elevation in the anterior and septal regions on the ECG, and characteristic increases in serum troponin levels. However, inadequate contrast filling on invasive angiography could prevent visualization of the culprit vessel, perhaps an occluded side branch of the LAD. In such a situation, even though infrequent, CT provides valuable diagnostic information, clearly depicting a high-grade stenosis or occlusion.

Occasionally, coronary CTA is used to clarify a finding of invasive angiography. One example is stenosis of the left main coronary artery, which sometimes is difficult to assess by invasive angiography. Figure 6 offers another example—in this case, a 54-year-old patient with possible dissection of the proximal LAD, which was suggested by the persistence of a small amount of contrast material after each injection. Intravascular ultrasound is one option for clarifying this finding. However, coronary CTA clearly shows

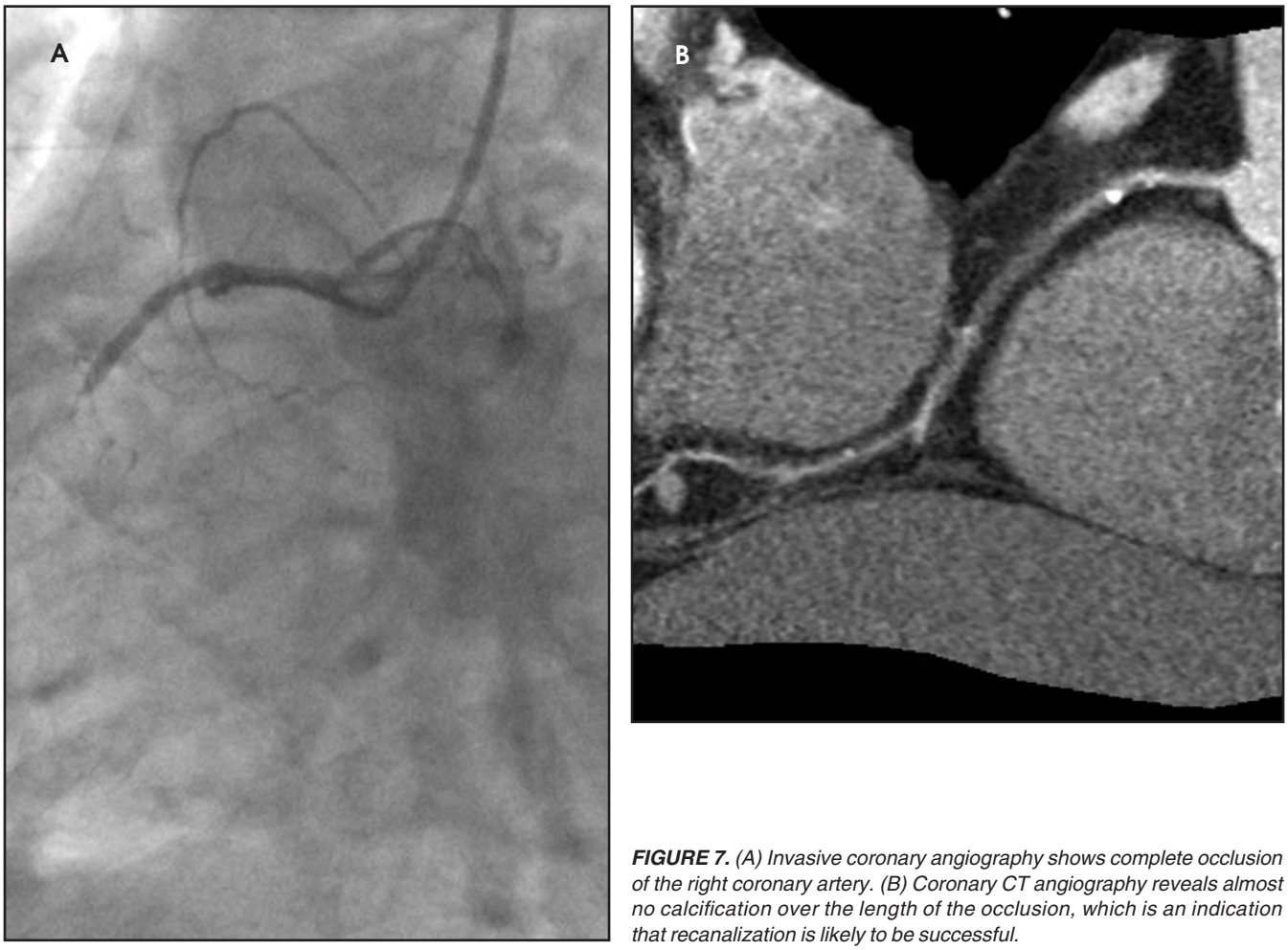

FIGURE 7. *(A) Invasive coronary angiography shows complete occlusion of the right coronary artery. (B) Coronary CT angiography reveals almost no calcification over the length of the occlusion, which is an indication that recanalization is likely to be successful.*

that the proximal LAD is completely normal, suggesting that the persistence of contrast material merely results from a flow phenomenon.

Coronary CTA may also be able to provide useful information before percutaneous coronary intervention of certain lesions. A study by Mollet et al[17] found that in patients with chronic total occlusion of the coronary arteries, CT predicts the success of recanalization more reliably than invasive angiography. In Figure 7, invasive coronary angiography shows complete occlusion of the right coronary artery. CT angiography reveals almost no calcification over the length of the occlusion—an indication that recanalization is likely to be successful.

It is also possible for coronary CTA to provide information on bifurcation angles or plaque burden that could be useful for the interventionalist. This application of coronary CTA is promising but is still unproven.

Conclusion

The role of coronary CTA is in transition. In the past, it was performed only by experienced operators in selected patients. Based on these early excellent results, and with continuous improvements in technology, more cardiologists and radiologists are undergoing training and education. As a result, the availability of reliable coronary CTA is becoming more widespread, and coronary CTA is increasingly being incorporated into the clinical work-up of cardiology patients.

Of the Top 10 indications for coronary CTA, the most important is to rule out coronary artery stenosis. In a clinical setting, this use of coronary CTA is most appropriate in patients with a low-to-intermediate likelihood of coronary artery disease—for example, those with stable, atypical chest pain; those with equivocal findings of myocardial ischemia on other forms of diagnostic testing; and, potentially, those who come to the emergency room with chest pain of uncertain origin.

Initial clinical experience with coronary CTA should focus on the types of patients in whom good-quality images can be obtained. These include patients with a low and regular heart rate; with a reasonably normal body weight (obesity can create excessive image noise); and without established coronary artery disease, since severe calcification, bypass grafts, and stents complicate the interpretation of CT scans.

References

1. Hoffmann MH, Shi H, Manzke R, et al. Noninvasive coronary angiography with 16-detector row CT: Effect of heart rate. *Radiology.* 2005;234:86-97.

2. Schuijf JD, Bax JJ, Shaw LJ, et al. Meta-analysis of comparative diagnostic performance of magnetic resonance imaging and multislice computed tomography for noninvasive coronary angiography. *Am Heart J.* 2006;151:404-411.
3. Stein PD, Beemath A, Kayali F, et al. Multi-detector computed tomography for the diagnosis of coronary artery disease: A systematic review. *Am J Med.* 2006;119:203-216.
4. Budoff MJ, Achenbach S, Blumenthal RS, et al. Assessment of coronary artery disease by cardiac computed tomography: A scientific statement from the American Heart Association Committee on Cardiovascular Imaging and Intervention, Council on Cardiovascular Radiology and Intervention, and Committee on Cardiac Imaging, Council on Clinical Cardiology. *Circulation.* 2006;114:1761-1791.
5. Mollet NR, Cademartiri F, Krestin GP, et al. Improved diagnostic accuracy with 16-row multi-slice computed tomography coronary angiography. *J Am Coll Cardiol.* 2005;45:128-132.
6. Hoffmann MH, Shi H, Schmitz BL, et al. Noninvasive coronary angiography with multislice computed tomography. *JAMA.* 2005;293:2471-2478. Erratum in: *JAMA.* 2005;294:1208.
7. Achenbach S, Ropers D, Pohle FK, et al. Detection of coronary artery stenoses using multi-detector CT with 16 x 0.75 mm collimation and 375 ms rotation. Eur Heart J. 2005;26:1978-1986. Comment in: *Eur Heart J.* 2005;26:1942-1944.
8. Leschka S, Alkadhi H, Plass A, et al. Accuracy of MSCT coronary angiography with 64-slice technology: First experience. *Eur Heart J.* 2005;26:1482-1487.
9. Raff GJ, Gallagher MJ, O'Neill WW, Goldstein JA. Diagnostic accuracy of noninvasive angiography using 64-slice spiral computed tomography. *J Am Coll Cardiol.* 2005;46:552-557. Comment in: *J Am Coll Cardiol.* 2006;48:219; author reply 219.
10. Leber AW, Knez A, von Ziegler F, et al. Quantification of obstructive and nonobstructive coronary lesions by 64-slice computed tomography: A comparative study with quantitative coronary angiography and intravascular ultrasound. *J Am Coll Cardiol.* 2005;46: 147-154.
11. Mollet NR, Cademartiri F, van Mieghem CA, et al. High-resolution spiral computed tomography coronary angiography in patients referred for diagnostic conventional coronary angiography. *Circulation.* 2005; 112: 2318-2323. Comment in: *Circulation.* 2005; 112:2222-2225.
12. Ropers D, Rixe J, Anders K, et al. Usefulness of multidetector row computed tomography with 64- x 0.6-mm collimation and 330-ms rotation for the noninvasive detection of significant coronary artery stenoses. *Am J Cardiol.* 2006;97:343-348.
13. Nikolaou K, Knez A, Rist C, et al. Accuracy of 64-MDCT in the diagnosis of ischemic heart disease. *AJR Am J Roentgenol.* 2006;187:111-117.
14. White CS, Kuo D, Kelemen M, et al. Chest pain evaluation in the emergency department: Can MDCT provide a comprehensive evaluation? *AJR Am J Roentgenol.* 2005;185:533-540.
15. Savino G, Herzog C, Costello P, Schoepf UJ. 64 slice cardiovascular CT in the emergency department: Concepts and first experiences. *Radiol Med (Torino).* 2006;111:481-496.
16. Gallagher MJ, Ross MA, Raff GL, et al. The diagnostic accuracy of 64-slice computed tomography coronary angiography compared with stress nuclear imaging in emergency department low-risk chest pain patients. *Ann Emerg Med.* 2006; doi:10.1016/j.annemergmed.2006.06.043
17. Mollet NR, Hoye A, Lemos PA, et al. Value of preprocedure multislice computed tomographic coronary angiography to predict the outcome of percutaneous recanalization of chronic total occlusions. *Am J Cardiol.* 2005;95:240-243.

Discussion

ELLIOT K. FISHMAN, MD: When you try to determine what the degree of stenosis is, or grading stenosis, what system do you use? What do you think is a good way of grading stenosis these days, knowing the limitations or advances in technology?

STEPHAN ACHENBACH, MD: Well, as we noted in the previous discussion, we cannot give an accurate percent grading of a stenosis. The spatial resolution of CT is just not there. So you have to talk in categories and, of course, you have to consider categories that are useful for the clinician who will make a decision on what to do with the patient. In a good-quality scan, I would say, "This is not a significant stenosis." This would be anything below 50%—that's a category I like to put forward. Then there's the clearly high-grade stenosis, which is anything >70%. If there's something in between these categories, meaning that I see a lesion, but I cannot reliably say whether it's a high-grade lesion or not, that's when I would say 50% to 70% in the report. I would also say some further testing needs to be done to determine whether or not you want to do an angiogram.

FISHMAN: When you try to grade it, I agree, there's no magic ruler you can put there. But what do you look at? Do you look at the vessel pre- and poststenosis? Do you try to look at cross-sectional anatomy? What do you find most helpful to you?

ACHENBACH: Since clinically we are comparing the CT angiograms to the invasive angiogram, it's important to look at the lumen, and only at the lumen, when you make a clinical assessment. If you look at the cross-section, and you have extensive remodeling, you will severely overestimate the degree of stenosis in comparison to the invasive angiogram since the invasive angiogram doesn't see the remodeling. The invasive angiogram only compares the lumen proximal to the stenosis, in the stenosis, and distal to the stenosis.

So you really have to force yourself to do the same thing when you look at the CT scan. That's what we do. We look at the lumen proximal to, in, and distal to the stenosis.

SAMUEL WANN, MD, MACC: Stephan, do you find a systematic overestimation of stenosis by CT?

ACHENBACH: "Systematic" is a difficult word, because it is also possible to underestimate. But more frequently, you will overestimate stenosis than underestimate. One thing I have observed, and I think many others have, is that the presence of calcium, especially, leads to the overestimation of stenosis. We tend to fear that calcium might obstruct stenosis, and you wouldn't see it. But what really happens is that calcium causes the overestimation of stenosis, because of artifacts associated with calcium and very–low-intensity artifacts caused by a little motion in the coronary. But, more often than not, calcium leads to overestimation of stenosis.

WANN: Is it fair to think of calcium as being inside the wall and not in the lumen, in most cases? Is it like calcified mitral annulus that we see on the echo all the time? The calcium is not actually in the ventricle; the appearance is caused by a blooming artifact. Is that a reasonable way to think about it for CT as well—that the calcium is most often a healing process in the wall?

ACHENBACH: It's in the wall, but it's not known whether it is due to healing or not. You could have probably a debate for weeks about that. More often than not, calcium is in the wall and not actually encroaching on the lumen. Many experienced people even say that if you have a dense calcification, there is usually no high-grade stenosis associated with it. At least, often there is no high-grade stenosis, but it's not always the case. But, as I said, more often than not, if you have severe calcification, there's no stenosis and the tendency is rather to overestimate.

WANN: We always worry about the calcium and not being able to see behind the vessel, as you pointed out. I think that

is a major concern, but it seems to me that, in day-to-day practice, a bigger concern is that when we see calcium, we overestimate stenosis, and the severe calcified lesions often aren't stenotic. For one reason or another, when you go to the cath lab, they're just not.

ACHENBACH: I absolutely agree. I don't want to encourage people to assume that if there's a lot of calcium proximally, there's no lesion. We should be careful not to put forward a strategy like that. But as you said, more often than not, severe calcium will cause overestimation of stenosis.

WANN: Another question that's been raised by a number of people is about the negative predictive value of CT angiography. Those numbers have been carried out in people who've undergone catheterization. But those are generally the moderate-risk patients; they're not the very–low-risk patients. In the emergency room, for example, to carry that low risk or negative predictive value, we really need to look at people in the emergency room who have a true low risk, who may or may not go to the cath lab. But, that data—correct me if I'm wrong—is just not available right now.

ACHENBACH: That's absolutely true. We can expect that the negative predictive value will remain very high.

WANN: But the Bayes' theorem says that anything that you see in a low-risk group has a higher likelihood of being artifactually wrong. We really need to do that study.

ACHENBACH: I think the Bayes' theorem would say that you have more false positives in the low-likelihood group than you have in the high-likelihood group.

WANN: Yes.

ACHENBACH: So, we're not too worried about it. We can always stay on the safe side. I think of the CT angiogram as a filter before the invasive angiogram. There are patients in whom you consider doing an invasive angiogram, but you use the CT first to try to avoid the invasive angiogram. So whenever we cannot clearly rule out the presence of stenosis by CT, either because we see a stenosis in CT, or because the image quality is not good enough to rule out the presence of stenosis, then the patients have to have the angiogram that was initially considered anyway. They're trying not to create more invasive angiograms by scanning anybody by a CT; and everybody in whom image quality is not good or in whom findings are questionable has to go to the cath. We don't want that. I want to use CTA as a filter in patients who are considered for cath, and if then the CT is normal, then you don't have to do that cath.

WANN: What are your thoughts? I know some people are actually fusing the CT data in the cath lab to expedite the cath, to cut down on radiation, to choose views, and to measure stent length. Do you think that there is any future in actually moving the CT into the cath lab, not to replace fluoroscopy, but to supplement it?

ACHENBACH: I think that's an interesting concept. I don't think you will have tremendous savings in radiation dose. One thing we do in our institution, for example, is if we have a patient in whom we saw a LAD stenosis on the CT scan, when we do the right, we'll visualize the right coronary artery with a diagnostic catheter, and we'll use a guiding catheter right away to visualize the LAD. So it saves time, saves radiation, and also saves some of the contrast material. So, we do incorporate what we know from CT into the cath lab procedure.

WANN: Correct me if I'm wrong, but there are ways to actually marry the digital data in PET, SPECT, and the cath lab directly with the digital data with registration of the data. For example, in the EP laboratory, we are using that on a daily basis to assist our EP physicians in mapping procedures. Is that a wave of the future, too, do you think?

ACHENBACH: Probably yes. I think it's going to be very, very difficult to have very accurate matching of CT data and invasive angiographic data because you have the motion or patient position that might be a little bit different. Often, a patient is breathing during the cath procedure. I have my personal doubts as to whether or not you can get co-registration with an accuracy of <1 mm, which would be necessary.

WANN: It would be easier in the atrium than in the coronaries for sure.

ACHENBACH: Yes. For EP, for perfusion and anatomy in CT, its accuracy doesn't have to be down to 1 mm, yes, I would be very hopeful. If you have something that has to be super accurate, it's probably theoretically possible, but hard to accomplish.

FISHMAN: You're right. It's just like looking at PET/CT, when you're trying to do a 3- or 4-mm difference over time, it's not a big deal, but getting less difference than that is very, very hard unless acquisition is done at the same time. It's very hard to merge data sets.

There's another point you made that is important to go back to, because I think we have all had the same experience. When you first start doing cardiac CT, you tend to overestimate all lesions rather than underestimate. I think the fear is that you will miss a patient who needs to go to the cath. Particularly in the presence of calcification, as you say, that's where the greatest variability between individual readers would be with more or less experience. Some software now does do those measurements, or at least tries to calculate areas in terms of CT. That, indeed, may be helpful in giving some quantification.

ACHENBACH: I think the software tools are helpful, but they only work if you have optimal image quality, because the software will not automatically recognize artifacts. It all comes down to what we have heard over and over again today. You have to have high-quality data sets to work with.

FISHMAN: Absolutely. You mentioned dual-source CT. Do you use beta-blockers in those patients?

ACHENBACH: Currently, we don't use beta-blockers in dual-source CT. It is definitely the case that dual-source CT can deal with higher heart rates than 64-slice CT, and still yield high-quality data sets.

FISHMAN: What's your definition of a high heart rate?

ACHENBACH: With 64-slice CT, anything >60 bpm is a high heart rate. With dual-source CT, we can easily cope with that. We just don't have enough patients yet to tell us how accurate we are in heart rates even higher than that.

WANN: Stephan, what is your opinion about presentations at the recent SCCT meeting using another approach, the use of a 256-slice scanner to completely avoid retrospective gating or spiral scanning? That also has a potential advantage in terms of reducing radiation dose and even increasing temporal as well as spatial resolution.

ACHENBACH: I think it will happen. I think we'll see the merging of two technologies in the future. The people who have 256-slice CT will probably introduce a second tube, or increase rotation time to improve the temporal resolution. Those people who have 2 sources will probably make the detectors wider. I think they will converge sooner more likely than later.

WANN: So, you're reasonably confident that our temporal resolution will improve and our radiation dose will go down in the next couple of years?

ACHENBACH: Yes. Temporal resolution will improve and radiation dose will decrease. But I'm not so confident that spatial resolution will make tremendous advances, because spatial resolution is immediately tied to radiation exposure. If we want to double our spatial resolution, we have to increase the radiation exposure by a factor of 4. So unless we have other means of reducing radiation, I see a limit to really improving spatial resolution.

WANN: Does contrast dose affect spatial resolution?

ACHENBACH: Contrast concentration probably does. I think high contrast concentration is a good thing. Whether it directly influences spatial resolution, I'm not sure.

WANN: There was a mention earlier of using the saline flush to reduce potential toxicity from the contrast. Is that proven? Is a smaller contrast dose directly related to nephrotoxicity?

ACHENBACH: Well, I think a higher dose is related. If you use 60 or 80 mL, it probably wouldn't translate into a measurable clinical difference. But, less contrast is safer, especially if you think about the combination of studies, such as if you do CT scan, and if you find something, you need to do the invasive angiogram right after it.

FISHMAN: Nephrotoxicity is definitely related to contrast volume; there's no doubt. If you look at the literature, as Stephan is alluding to, if you use <100 mL contrast in most patients, there's not going to be any issue in terms of nephrotoxicity showing up 3 days out.

WANN: That's really my question. Is there a difference between 80 and 100?

FISHMAN: At that level, really, there is probably not a difference, except in some borderline patients.

ACHENBACH: If you do 150,000 patients, you will probably see a difference.

MATTHEW BUDOFF, MD: Well, actually, they have done pretty large data sets, mostly with CTs of noncardiac structures, that are actually in a pretty good range. They have not found a dose relationship to nephrotoxicity, so maybe it's not going to the wide enough ranges. But there is no difference between 60 and 80 or 80 and 100 mL.

ACHENBACH: I have a feeling that many people use too much contrast in CT angiography of the coronaries. Often I hear people using 100 to 120 mL, even with a 64-slice scanner, where the acquisition is only about 10 seconds. When you only have an acquisition time of 10 seconds, you only need full contrast for the duration of 10 seconds. So, I think we can do with substantially less contrast than most investigators currently use.

WANN: It is intuitive that less contrast is better, but as Dr. Budoff has said, there's not a whole lot of proof that very low doses of contrast are, in fact, safer, although very high doses seem to be bad.

BUDOFF: Well, in the cath lab, we routinely avoid doing angiograms in patients with renal insufficiency, although there's absolutely no science here. It might make us feel better; it probably doesn't make the kidneys feel better. But it's something that's translated from common sense into common practice without a lot of science behind it. I think Stephan's other point, though, is more important: That if we are willing to go from the CT to the cath lab, then sparing radiation and contrast up front, if we're going to repeat that in some capacity, is even more important.

FISHMAN: Forgetting cardiac cath or cardiac CT for a second, the more important factors in patients who develop nephrotoxicity in large hospital studies are multiple studies over short periods of time. Once you go from 1 study to 2 studies within 24 hours, that's really where the toxicity picks up.

Further on toxicity, I have a question in terms of using specific contrast agents, such as isosmolar agents. Has anyone routinely used isosmolar contrast for cardiac CT or cath?

JILL E. JACOBS, MD: We do. We actually alternate between Visipaque and Ultravist.

JAMES K. MIN, MD: We exclusively use Visipaque for all of our coronary CT scans.

FISHMAN: So do we. Why do you do that?

MIN: I like the contrast enhancement with 320 mgI/mL. We started with Isovue at 370, we went down to 270. I just like the safety profile of Visipaque, and I think that the contrast enhancement supports visualization of even minimal soft plaque abutting the arterial wall.

FISHMAN: There have been articles, more from the cardiac cath literature, that have shown that the isosmolar agents do not affect the heart rate as much. So, once you inject, you don't have that little bump of 5 to 7 beats, so that would be another good advantage. In our practice, we routinely use it.

WANN: We switched to an isosmolar agent because of the heart rate variability. We didn't do a systematic study, but a few patients would show a heart rate bump, and the technical quality of the study wasn't optimal. With an isosmolar agent, we don't get the flushing or quite as much heart rate variability. I haven't quantified that, but that's our rationale for using it as well.

FISHMAN: Another point about heart rate, from the technical perspective, is that the technologist needs to be very careful figuring out how the patient's heart rate reacts to contrast, particularly in the test bolus. You can get a feel that some patients' heart rates go up quickly. I don't care if they've had beta-blockers or not; a lot of patients just get very apprehensive when the machine starts humming, their heart rate goes up, and then it quickly comes down. So, we'll often watch that and will test patients. Then you'll know if you have to wait a few more seconds before you start the study.

JACOBS: I think the other thing is that when you're testing patients, and you've given them beta-blockers, you have to remember that sometimes in full inspiration you can get significant bradycardia compared to rest. So you always want to test them, in inspiration.

WANN: There seems to be a divergence of opinion about using bolus tracking versus test bolus. We have used bolus tracking from the beginning, and find it very useful and very easy. So we have never done test boluses. But I understand others rely on test boluses for this kind of thing.

MIN: Well we don't have the option. On the GE scanner, you can't do an automated bolus detection. So you just end up doing a timing bolus.

BUDOFF: Oh, no, for the GE, we have done bolus tracking. We actually switched from it. I still prefer the test bolus, because I think it gives me a chance to test the IV, to look at the heart rate variability and to see how the patient responds to the contrast. It gives the patients a first chance to get warm from the contrast, if they are going to get that. This way, when they get a bigger dose, it's not as big a deal to them. But, at our other site, where we use VCT, they exclusively use bolus tracking and they don't use a test bolus. But the results have been good, and the image quality has been good, so I haven't been able to tell them that that's not appropriate. The technologists are very, very experienced and have done, you know, 6,000 or 7,000 of these, and they really feel comfortable with bolus tracking. But that is on the GE VCT systems, so it's definitely available.

FISHMAN: We did test bolus, but when you look at the literature, as long as you can do one of them well, it's perfect. We tell people probably the same thing you tell people—just do it one way. Don't do it both ways because then it won't work.

WANN: Make it simple. It's very confusing to switch back and forth.

FISHMAN: Pick one that will work for your technologists. If they're happy with, leave it alone.

WANN: Well, as long as we're talking about contrast injections, tell me about this saline chaser and the advisability of using a half-saline, half-contrast mix. We're not having much problem with what we're doing, so I've no need to change. I believe isosmolar agents are slightly more viscous. Is there more of a need to flush out the vena cava?

ACHENBACH: We like the saline chaser to keep the contrast compact and really push all the contrast into the left heart. So we have the saline chaser to keep up the high enhancement in the left heart. What we have started doing recently, mainly because our radiologists also gave some input, is to not inject a pure saline chaser, but to mix 80% saline and 20% contrast, which gives a little better opacification of the right heart.

WANN: Does that affect the triple rule-out, in looking at the pulmonary arteries?

ACHENBACH: It can. It does improve visualization of the pulmonary arteries. So, if you really want to include the pulmonaries, even though you only have a very limited range of the pulmonaries, so you don't get the complete rule-out of pulmonary embolism. But it improves visualization of that a little bit.

FISHMAN: Yes, I think that 80%/20% comes along when you want to use some automated software for the chamber volume. That's really where it comes in.

ACHENBACH: As long as it's in cardiology, we don't care about the right heart.

WANN: That seems to be vendor specific, too, because we don't have any problem with right-heart volumes, so we don't use the 80%/20%.

FISHMAN: Yes. I think a little bit depends also on the injector. Like, for example, I think if you have a Stellant injector from Medrad, you can do that contrast and saline mix. If you don't have that injector, it's more of an issue.

ACHENBACH: It depends on the amount of contrast. If you use 80 or 100 mL of contrast, you don't need to mix to get opacification of the right heart. But, since we try to keep our contrast volume really, really low, and we often scan with 50 or 55 mL of contrast, and then the contrast is completely out of the right heart when we scan.

WANN: We use saline to test the IV, to make sure it's open, and we tell our patients they're going to feel warm and they believe this. We don't have to demonstrate it.

BUDOFF: We've actually shown that you get a better top-to-bottom uniform opacification of the aorta and all the cardiac structures if you do chase the saline out of the veins. You did get a lot of hang-up of contrast, so you can use a lot less and be more efficient with your contrast, especially if you're doing multiple studies.

WANN: I think one of the potential advantages of the 256-slice CT scanner in acquiring the entire cardiac cycle without retrospective gating is that you don't get the variation in contrast because you're not doing reconstructions. You've got the whole heart acquired simultaneously, and you don't see that gradation of contrast, which, even with a saline bolus, we sometimes notice through the image.

FISHMAN: We'll stop on that point, and say that the scanning and contrast technique is critical.