How to perform coronary CTA: A to Z

Attention to the details of contrast administration and data acquisition pays off in excellent image quality.

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Coronary computed tomographic angiography (CTA) is proving to be an accurate technique for the noninvasive evaluation of coronary artery disease and coronary artery anomalies. At the same time, it enables the evaluation of the cardiac chambers, myocardium, and valves. This article will review the strengths and limitations of coronary CTA, its potential applications, and the techniques used in image acquisition and contrast administration.

Coronary CTA has several important advantages: it is noninvasive, can be performed quickly, and provides both intra- and extraluminal information. Its disadvantages include radiation exposure, the need for intravenous (IV) contrast administration, and the need for beta-blockade in most patients.

An absolute contraindication to coronary CTA is the inability to tolerate IV contrast material. Relative contraindications include cardiac arrhythmias, extensive calcification of the coronary arteries, and a rapid heart rate.

Appropriate candidates for coronary CTA include the following: patients with atypical chest pain syndromes; those who are at low-to-intermediate risk for coronary artery disease with either equivocal or abnormal results from a previous nuclear scan, stress test, electrocardiogram (ECG), or echocardiogram; those with cardiovascular risk factors, such as hypercholesterolemia, hypertension, diabetes, and smoking; those with a strong family history of cardiovascular disease; those with possible coronary anomalies in need of further anatomical delineation; and those who have undergone coronary revascularization, including coronary artery bypass grafting and stenting (Figure 1). (The quality of imaging in patients with coronary stents is variable, however.)

Technical parameters

Key technical requirements for coronary CTA are high temporal resolution (which minimizes motion artifacts and is achieved through fast gantry rotation), high spatial resolution (which enables detailed depiction of the coronary anatomy and is achieved through thin collimation), fast continuous coverage (which enables imaging of the entire heart in one comfortable breath-hold and is achieved through multislice CT), and synchronization to the heartbeat (which enables imaging during a consistent cardiac phase and is achieved through ECG gating).

Conventional cardiac catheterization has a temporal resolution of 20 msec. Even the most advanced CT scanners cannot yet match this benchmark; however, CT technology is progressing rapidly. Sixty-four-slice CT scanners have a temporal resolution of 165 msec, and new dual-source CT scanners, 83 msec. With segmented reconstruction algorithms, dual-source CT has the potential to achieve a temporal resolution of 42 msec.

Just as with temporal resolution, the spatial resolution of advanced CT scanners does not yet equal that of conventional catheterization. CT technology is approaching the 0.2-mm standard set by conventional cardiac catheterization, however. Sixty-four-slice CT scanners have a spatial resolution of 0.4 mm, and dual-source CT scanners have a spatial resolution of <0.4 mm.

Improvements in temporal and spatial resolution have markedly improved CT evaluation of coronary stenosis. Early studies of 4-slice CT demonstrated a negative predictive value of 97% to 98% and showed that CTA could reliably exclude the presence of coronary artery disease.[1-4] Positive predictive value was much lower, however, in the mid-60% range. More important, as many as 30% of segments were not assessable using 4-slice CT scanners.

In more recent studies conducted on 16- and 64-slice CT scanners, the negative predictive value remained very high (97% to 99%), but the positive predictive value increased significantly, to approximately the 80% range.[5-10] Most important, the percentage of assessable segments increased to 80% to 100%, indicating that coronary CTA could more reliably image small distal branches.

Protocols

The success of coronary CTA depends on obtaining a good data set the first time. Many of the steps that ensure acquisition of a good data set take place even before scanning begins. At New York University (NYU) Medical Center, friendly and competent staff set the tone. We bring patients into a calm atmosphere where the lights are dimmed and provide
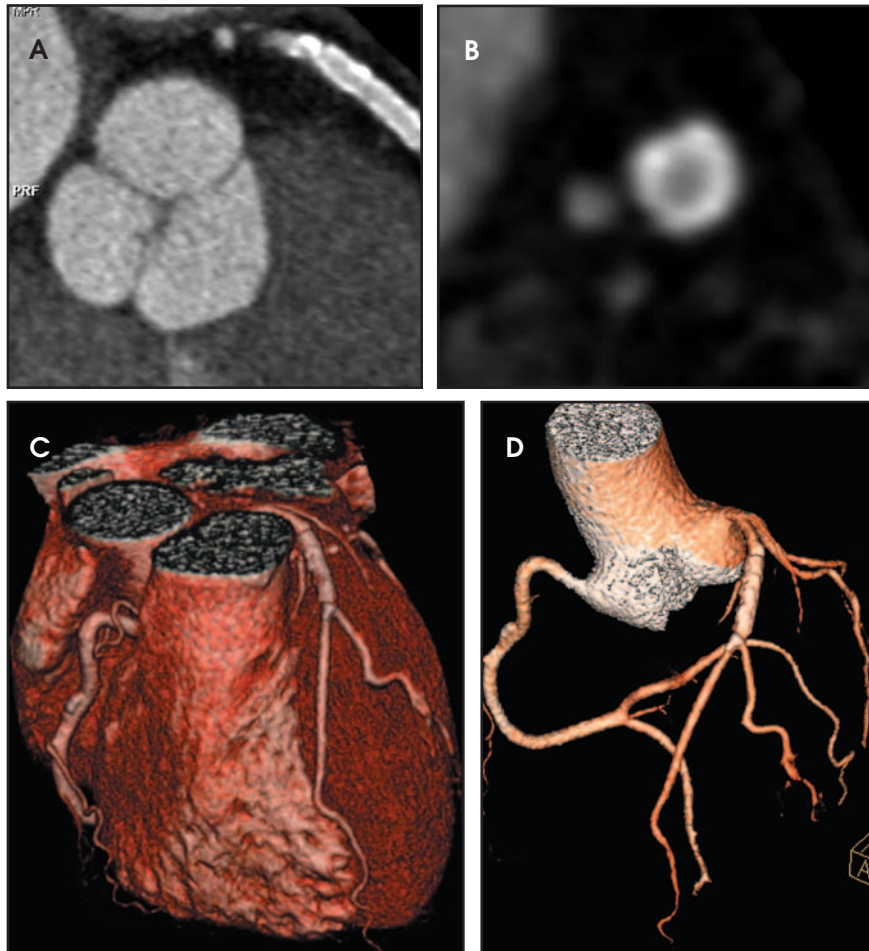
FIGURE 1. *A stent in the left anterior descending (LAD) coronary artery. (A) A sagittal multiplanar reconstruction shows the stent lumen and some calcification in the stent struts. (B) A short-axis view through the stent shows the stent struts and opacification of the lumen. (C and D) Volume-rendered images show the LAD stent and calcified plaque just beyond the stent. These images were acquired on a dual-source CT scanner.*

warm blankets to prevent shivering during the examination. We give patients explicit breathing instructions several times before starting the scan and even practice breathing with them. We emphasize the need to suspend respiration at the appropriate time and to stay still during the examination. We also minimize worry during the procedure by informing patients about the possible effects of contrast material, including warmth, a metallic taste in the mouth, and pelvic tingling. The ultimate goal is to convey a feeling of reassurance to the patient.

We begin the CT scan by obtaining a calcium score, scanning from the level of the tracheal bifurcation to the bottom of the heart. On a 64-slice CT scanner, we use a slice collimation of 1.2 mm and a slice width of 3 mm. We typically reconstruct with a B30f kernel.

The calcium score not only provides independent prognostic information, it also helps in determining whether a patient is a good candidate for coronary CTA. We do not have an absolute threshold coronary calcium score that precludes coronary CTA; however, in a patient with very dense calcification along the length of the coronary vessels and at multiple branch points, it is extremely difficult to interpret CTA images. Often, we will not proceed in such cases.

Sometimes, however, coronary CTA is warranted even in the face of a high calcium score. For example, a patient who is fearful of cardiac catheterization may be convinced to undergo the invasive procedure after seeing evidence of extensive coronary artery disease on CTA.

Conversely, because coronary CTA is able to detect noncalcified plaque, it may prove valuable even in a patient with a very low coronary calcium score. Figure 2 shows a 42-year-old man with elevated cholesterol, occasional chest pain, a family history of heart disease, and a coronary calcium score of 1. Coronary CTA revealed an eccentric noncalcified plaque encroaching on the lumen of the proximal left anterior descending (LAD) coronary artery, a finding that was confirmed by intravascular ultrasound.

Table 1 outlines the protocol we currently use in performing 64-slice coronary CTA. Just as with coronary calcium scoring, the scan range is from the tracheal bifurcation to the bottom of the heart; however, in patients who have undergone coronary artery bypass grafting, we extend the range to include the top of the chest, in order to identify the takeoff of the bypass grafts. We select an effective mAs of 700 to 900, a detector collimation of 0.6 mm, and a slice thickness of 0.75 mm. We typically use a pitch of 0.2, a rotation time of 0.33 sec, and a reconstruction interval of 0.5 mm. The technologist always positions the heart at the isocenter, and we reconstruct with a small field-of-view, thereby improving resolution.

Patient preparation for the 64-slice CT scanner includes instruction to consume nothing by mouth 3 hours prior to the study and to avoid caffeine the morning of the scan. If the patient's baseline heart rate exceeds 65 bpm, we administer beta-blockers—oral metoprolol 50 to 100 mg—45 minutes to 1 hour prior to the study, with the goal of achieving a heart rate of approximately 55 bpm. If the heart rate remains too high, we administer IV metoprolol in 5-mg doses, up to a maximum of 20 mg. It is important to use caution when administering beta-blockers to patients with asthma, severe aortic stenosis, atrioventricular block, or severe left ventricular dysfunction. We currently are not administering beta-blockers to patients imaged on the dual-slice CT scanner.
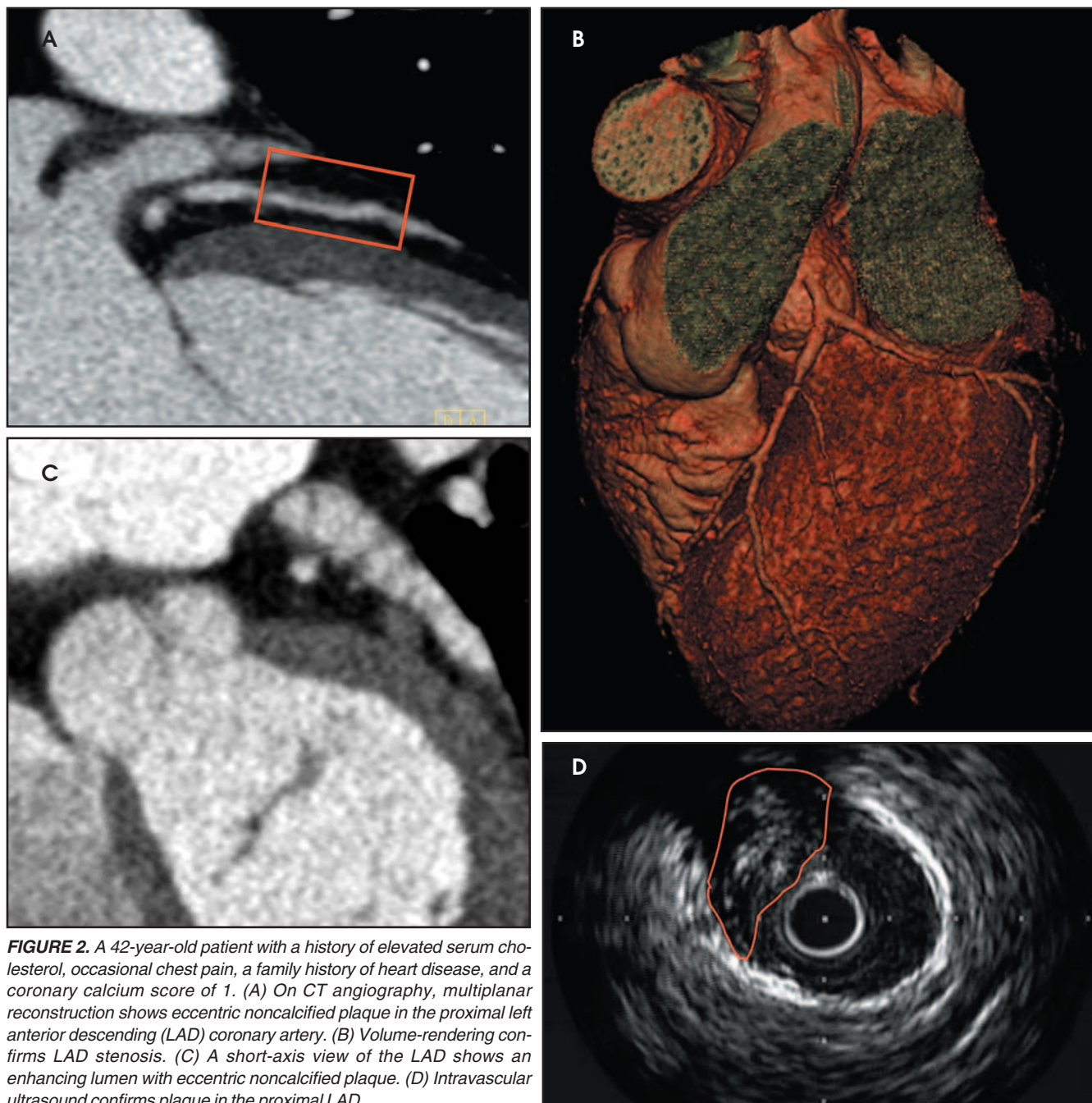
FIGURE 2. *A 42-year-old patient with a history of elevated serum cholesterol, occasional chest pain, a family history of heart disease, and a coronary calcium score of 1. (A) On CT angiography, multiplanar reconstruction shows eccentric noncalcified plaque in the proximal left anterior descending (LAD) coronary artery. (B) Volume-rendering confirms LAD stenosis. (C) A short-axis view of the LAD shows an enhancing lumen with eccentric noncalcified plaque. (D) Intravascular ultrasound confirms plaque in the proximal LAD.*

Immediately before the scan starts, we administer 0.4 mg sublingual nitroglycerin, except in those patients who have taken sildenafil citrate within 24 hours for erectile dysfunction, as the interaction between the 2 medications can precipitate hypotension.

We typically administer 50 to 100 mL of IV contrast material (iodixanol 320 mgI/mL) through an 18-gauge catheter in the right antecubital fossa. The contrast administration protocol comprises 3 phases. In phase 1, contrast volume is determined by the scan acquisition time. We simply multiply the scan time by 5 and inject at 5 mL/sec. In phase 2, we inject 7 to 10 mL of contrast material at 2.5 mL/sec. The goal of this phase is the opacification of the right side of the heart, in order to identify right-sided pathology and to define the intraventricular septum for future use in determining ejection fraction. In phase 3, we inject 50 mL of saline at 5 mL/sec.

The benefits of a saline chaser include greater arterial enhancement, a tighter contrast bolus, and a reduction in streak artifact resulting from contrast in the right side of the heart (Figure 3). A saline chaser also enables a reduction in contrast volume of 15% to 20%, which minimizes both cost and the risk of contrast-induced nephropathy.

Table 1. Coronary CTA protocol: 64-slice scanner

Coronary calcium scoring

Range	Tracheal bifurcation to the bottom of the heart
kV	120
Effective mAs	310
Slice collimation	1.2 mm
Slice width	3 mm
Pitch	0.2
Kernel	B30f

Coronary CTA

Patient preparation

NPO	3 hrs prior (no caffeine)
Beta-blockade*	Metoprolol po (50 to 100mg) 1 hr prior to scan 5 mg IV prn (20 mg total max)
Nitroglycerin†	0.4 mg sublingually
IV catheter	18-gauge, in (right) antecubital fossa

Scan parameters

Range	Tracheal bifurcation to bottom of heart
kV	120
Effective mAs	700–900
Detector collimation	0.6 mm
Slice thickness	0.75 mm
Pitch	0.2 (0.18 for heart rate <50 bpm)
Rotation time	0.33 sec (0.37 sec for heart rate <50 bpm)
Reconstruction interval	0.5 mm
Kernel	B30f (B46 for stents)

IV contrast administration

Contrast volume	50–100 mL total
Phase 1	Contrast (mL) = scan time × 5 @ 5 mL/sec
Phase 2	7 mL contrast @ 2.5 mL/sec
Phase 3	50 mL saline @ 5 mL/sec

*Use caution in administering beta-blockers to patients with asthma, aortic stenosis, atrioventricular block, or severe left ventricular dysfunction.
†Recent sildenafil use is a contraindication to the use of nitroglycerin.
CTA = computed tomographic angiography, NPO = nil per os (nothing by mouth); po = per os (by mouth); IV = intravenous; prn = pro re nata (when needed)

The saline chaser is just one of several contrast factors that, along with patient factors and scanning technique, affect arterial enhancement. Others include the total amount of iodine administered, the injection rate, and the concentration and viscosity of contrast material. The most important patient factors that influence arterial enhancement are body weight and cardiac output.

The scanning technique plays an equally important role. The use of an empiric, fixed scan delay is ineffective in coronary CT angiography. Instead, the timing of image acquisition must be individualized using 1 of 2 methods. Automatic bolus tracking involves injection of the full contrast dose plus the saline chaser. Monitoring scans track attenuation in the ascending aorta, and scanning is automatically triggered when aortic enhancement reaches a predefined threshold, for example, 200 HU.

We are currently using the test bolus technique, which involves injection of approximately 10 mL of contrast material at 4 to 5 mL/sec (the same rate as will be used during coronary CTA), followed by a saline chaser. A series of monitoring scans determines the time to peak aortic enhancement. The optimal scan delay is equal to the time to peak aortic enhancement plus 2 seconds.

ECG gating

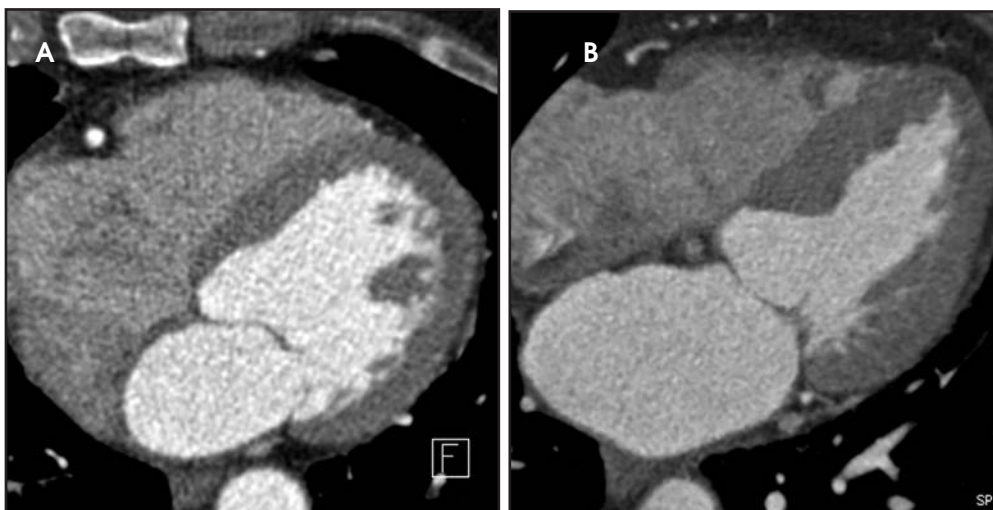It is important to incorporate cardiographic gating into coronary CTA in

FIGURE 3. Good scan and contrast administration techniques, including the use of a saline chaser, result in the dense opacification of the left side of the heart and the faint opacification of the right side of the heart. (A) A horizontal long-axis (4-chamber) view shows the right coronary artery and (B) a ventricle branch coming off of it. There is no streak artifact over the right coronary artery.
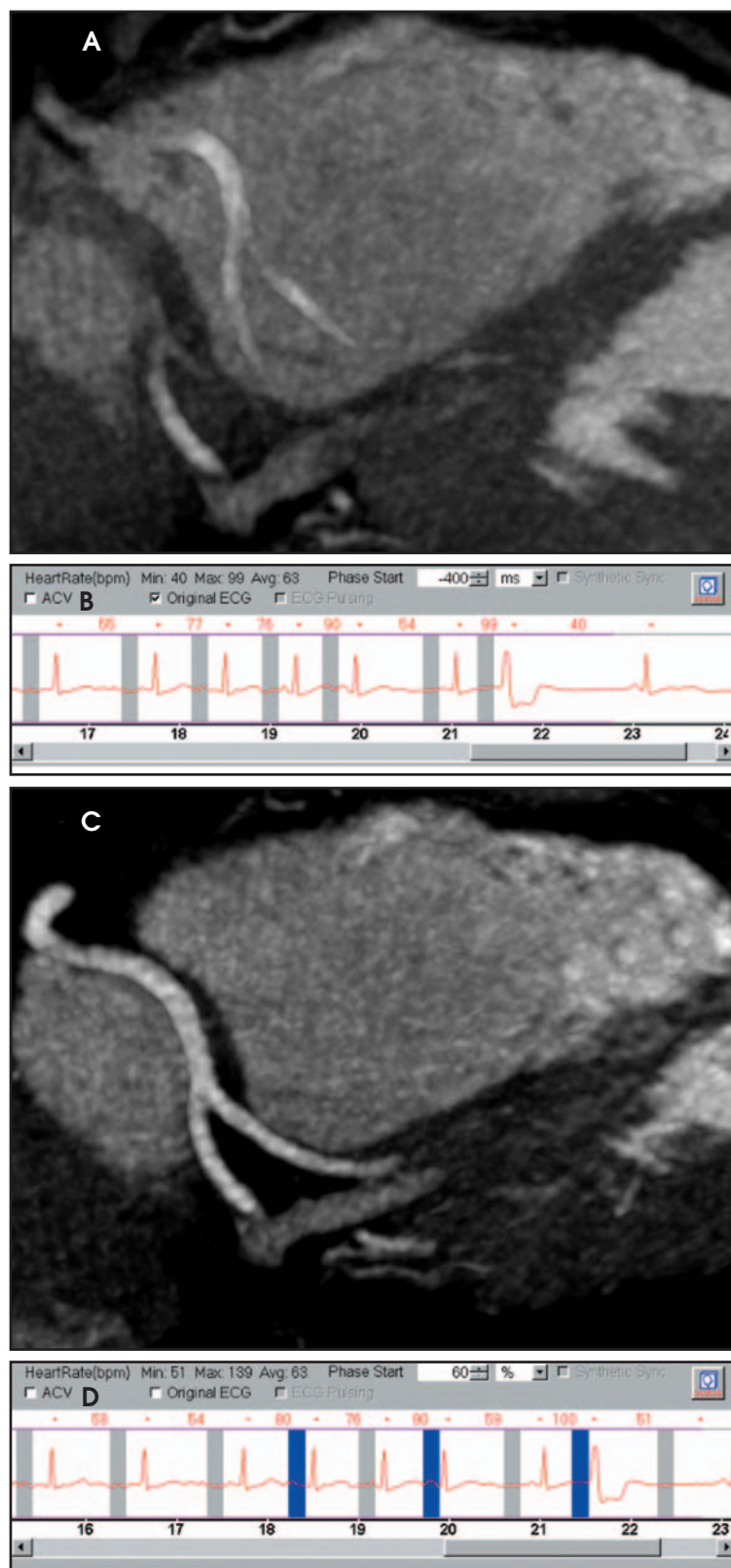
FIGURE 4. (A and B) An initial reconstruction at -400 msec in a patient with an irregular heart rhythm results in a duplication artifact. (C and D) Changing the reconstruction to 60% of the R-R interval yields an excellent motion-free image of the distal right coronary artery.
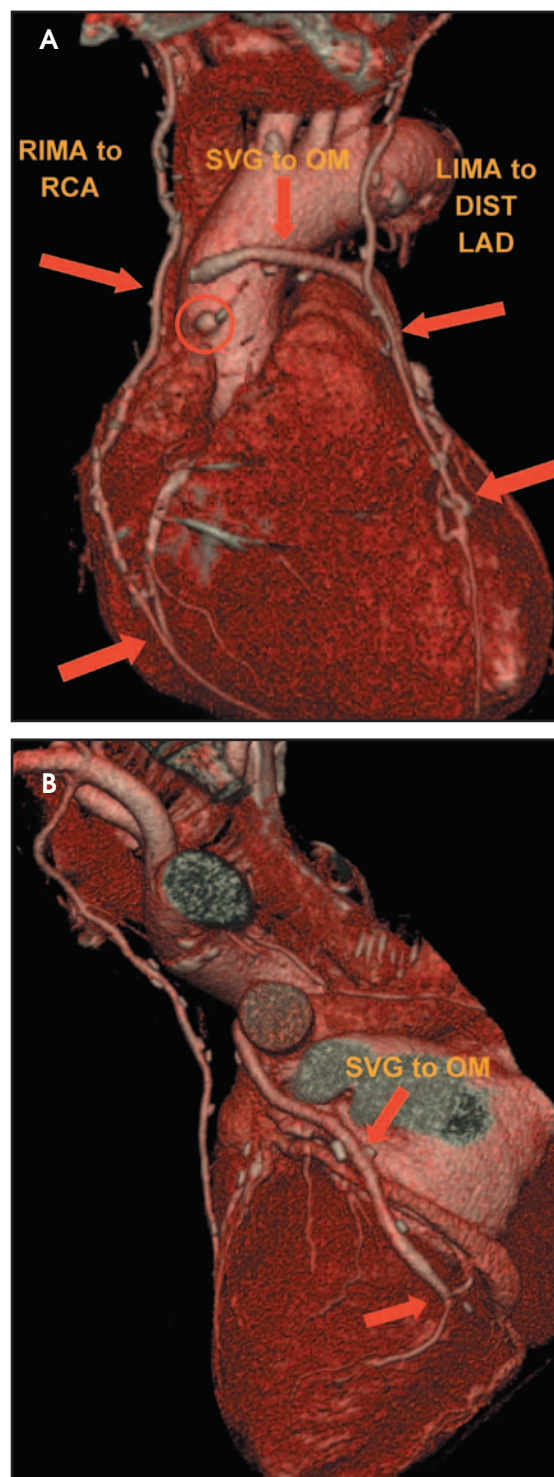
FIGURE 5. CT angiography in a patient with multiple coronary artery bypass grafts. (A and B) Volume renderings show takeoff and touch-down points of a right internal mammary artery [RIMA] graft to the right coronary artery [RCA], a left internal mammary artery [LIMA] graft to the distal left anterior descending [LAD] coronary artery, and a saphenous vein graft [SVG] anastomosis to the obtuse marginal [OM] branch. There is also an small portion of an occluded saphenous vein graft visible (circle).
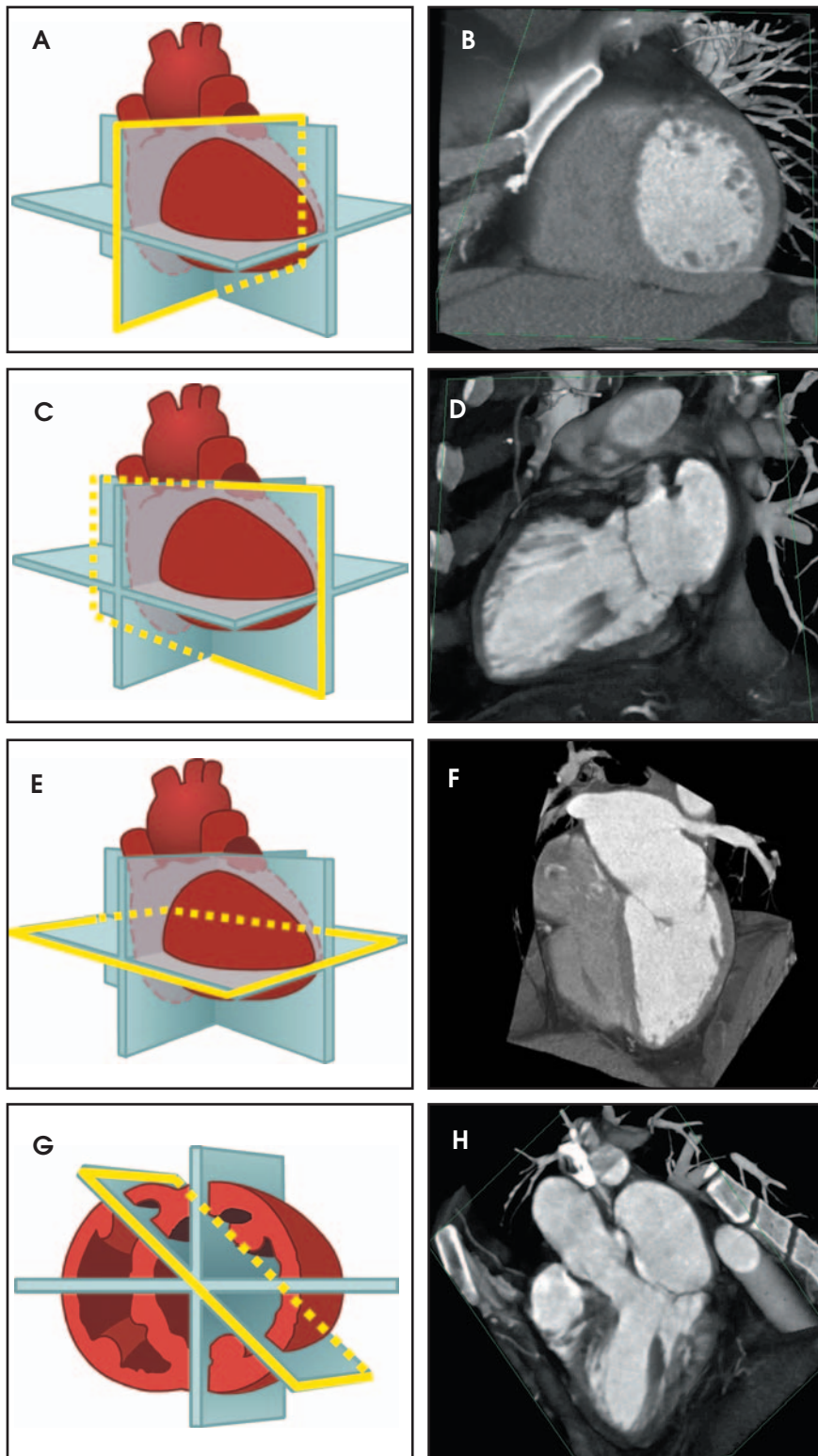
FIGURE 6. Biorthogonal views aid in the evaluation of cardiac structure and function. (A and B) A short-axis view enables the evaluation of myocardial contractility. (C and D) A vertical long-axis (or 2-chamber) view nicely shows the papillary muscles and mitral valve. (E and F) A horizontal long-axis (or 4-chamber) view reveals the cardiac chambers and valves. (G and H) A 3-chamber view enables the examination of the left ventricular outflow tract and the relationship between the mitral and aortic valves.

order to achieve motion-free images of the coronary arteries and aorta. One option, prospective ECG triggering, is a step-and-shoot sequential scanning method timed to coincide with a predefined point in the cardiac cycle. The advantages of prospective ECG triggering are speed and a reduction in radiation dose. One disadvantage is the need for a regular heart rate and rhythm. In a patient with an irregular heart rate, image acquisition can be triggered at the wrong point in the cardiac cycle, resulting in misregistration artifact. In addition, sequential scanning yields single transaxial slices rather than volumetric data, and z-axis resolution is suboptimal.

Therefore, coronary CTA is usually performed using retrospective ECG gating. Among the advantages of this technique is the ability to scan in spiral mode, which enables the acquisition of a volumetric data set throughout the cardiac cycle. Data from specific parts of the cardiac cycle are then retrospectively referenced to the ECG signal for image reconstruction, resulting in true registration of data to the ECG tracing. Additional advantages include isotropic z-axis resolution and reduced dependence on a regular heart rhythm.

Retrospective reconstruction can be done in 2 ways: using either a fraction of the R-R interval or an absolute time point prior to or following the R wave.[11] With the first option, 30%, 50%, and either 65% or 70% reconstructions are generally adequate. At NYU Medical Center, we reconstruct at 10% intervals throughout the cardiac cycle so that we can also evaluate cardiac function and valve motion. When using an absolute time point in the cardiac cycle, we typically reconstruct images at 350 msec, 400 msec, and 450 msec before the R wave.

The coronary arteries often move slightly differently from one another, so it is helpful to use a preview series of reconstructions to determine which is optimal for visualizing each coronary artery. For example, preview reconstructions done at 20%, 30%, 40%, and 50% of the R-R cycle may reveal that only the 30% reconstruction yields a motion-free image of the right coronary
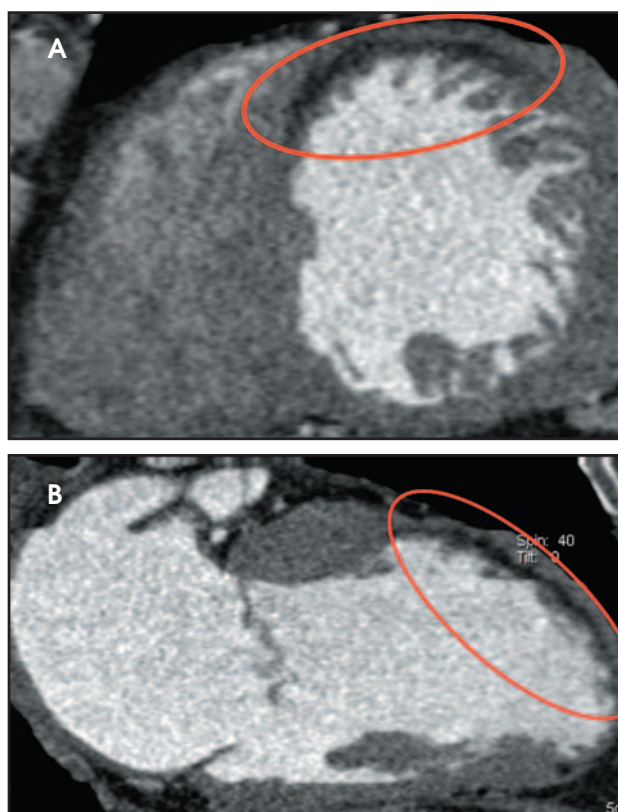
FIGURE 7. A 58-year-old man with a history of myocardial infarction. (A) The short-axis and (B) vertical long-axis views show an anteroapical perfusion defect with reduced attenuation in the subendocardium (circled). An evaluation of cardiac motion revealed hypokinesis in the region of the perfusion defect.

FIGURE 8. A patient with a large atrial septal defect. The horizontal long-axis (4-chamber) view clearly shows contrast material coursing between the 2 chambers.

FIGURE 9. The prolapsing portion of a defective mitral valve is easily seen on (A) vertical (2-chamber) and (B) horizontal (4-chamber) long-axis views.

artery. Similarly, in Figure 4, an initial reconstruction at -400 msec in a patient with an irregular heart rhythm resulted in a duplication artifact. With retrospective reconstruction, the data set can be edited to eliminate irregular beats. In this case, changing the reconstruction to 60% of the R-R interval yielded an excellent motion-free image of the distal right coronary artery.

An important disadvantage of retrospective ECG gating is an increase in radiation dose. Natural background radiation exposes each of us to approximately 2 to 5 mSv each year. According to manufacturer data, routine multislice chest CT delivers a dose of 5 to 7 mSv, and a diagnostic coronary catheterization delivers 5 to 10 mSv. Coronary calcium scoring performed on a 16-slice scanner exposes men to approximately 3 mSv and women to approximately 4 mSv. CTA delivers approximately 12 mSv to men and approximately 16 mSv to women.

Dose modulation programs can minimize radiation dose through ECG pulsing, which maintains the nominal tube output only during diastole, when it is most possible to obtain motion-free images of the coronary arteries. Tube output is then reduced to 20% during systole, which enables an overall reduction in radiation dose of up to 50%, depending on the patient's heart rate. ECG pulsing reduces the radiation dose associated with coronary calcium scoring on a 16-slice CT scanner to approximately 1.1 mSv and the dose associated with coronary CTA to 4.3 mSv.

The radiation dose associated with 64-slice CT systems depends on the scan protocol. For example, using an effective mAs of 850 and a collimation of 0.6 mm, the radiation dose to men in the absence of ECG pulsing is approximately 16 mSv, and to women, approximately 23 mSv. The radiation dose can be reduced significantly with ECG pulsing to approximately 10 mSv in men and 14 mSv in women. New dual-source CT systems are expected to reduce the radiation dose by approximately half that of 64-slice systems.

Postprocessing

The first step in evaluating coronary CTA images is to scroll through the axial data set. Axial images provide an overview of the data set and yield important information—for example, regions of plaque that warrant closer examination on biorthogonal projections, maximum intensity projections (MIPs), or curved planar reformations.

The next step is to examine MIP images through each of the coronary arteries. Most of the information on coronary artery stenosis comes from evaluation of the axial images in conjunction with MIP images and curved planar reformations. Curved planar reformations enable visualization of the entire course of an artery, making them helpful in the evaluation of not only native coronary arteries but also bypass grafts, including the origin and the distal anastomosis.

Volume renderings are also useful, especially for evaluation of complex anatomy, including bypass grafts (Figure 5), coronary artery anomalies, and other coronary artery abnormalities, such as fistulas. In addition, volume renderings are ideal for communicating the findings of coronary CTA to patients, who often request to see 3-dimensional colored images of their heart.

Most vendors offer automated systems for segmentation of the coronary arteries. These systems enable the user to place a seed point in the ascending aorta just above the origin of the coronary arteries. The system then automatically detects the coronary arteries and segments them out.

The degree of coronary artery stenosis can be reported either quantitatively or qualitatively. Automated software enables the user to place a point at the area of maximal stenosis and identify reference points of normal caliber superior and inferior to the area of stenosis. The system then calculates and reports quantitative percent stenosis. If referring physicians prefer qualitative reporting, a mild lesion is generally defined as <30% stenosis, a mild-to-moderate lesion as 30% to 50% stenosis, a moderate lesion as approximately 50% stenosis, a moderate-to-severe lesion as 50% to 75% stenosis, and a severe stenosis as >75%.

Multiplanar reconstructions and cine imaging offer additional perspective on the diagnosis of heart disease, one that moves beyond the coronary arteries to encompass not only other cardiac structures but also myocardial perfusion and function (Figure 6). For example, Figure 7 shows a 58-year-old patient with a history of myocardial infarction. The short-axis and vertical long-axis views demonstrate an anteroapical perfusion defect with reduced attenuation in the subendocardium. Wall motion analysis revealed hypokinesis in the region of the perfusion defect. Figure 8 shows a patient with a large atrial septal defect. The horizontal long-axis view clearly shows contrast material coursing between the 2 chambers. In Figure 9, the prolapsing portion of a defective mitral valve is easily seen.

Conclusion

Coronary CTA offers many advantages to patients and physicians. Not only does coronary CTA offer a noninvasive, fast means of visualizing both calcified and noncalcified plaque, but it is also a highly accurate tool for the evaluation of coronary artery stenosis. In addition, CTA provides valuable information on the cardiac chambers, myocardium, and cardiac valves.

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Discussion

ELLIOT K. FISHMAN, MD: Thanks very much, Jill, for that terrific talk. Let me ask a couple questions, and then we'll open the discussion with the panel. In terms of all those beautiful images you showed, who exactly does that imaging in your practice? Is it you or is it a technologist doing the work?

JILL E. JACOBS, MD: We do it with the technologist, and there's always a physician present at the scanner. We work together, and then the physician does the postprocessing. Our technologist will do the volume-rendered images for us, because most of the time we're not actively looking at them during image interpretations, so they'll do the volume-rendered images that get sent to our referring physicians. But other than that, the physicians are actively there.

FISHMAN: When you do the postprocessing, are you interactively processing and dictating at the same time, basically?

JACOBS: Yes. We're looking through the data set, and then we'll do our MIP images. If we see pathology, we'll do an image and annotate it for the referring physician so they see what we're seeing. We just quickly take that image, and we are the ones interacting with the data set and producing images.

FISHMAN: What do you send to the referring physician?

JACOBS: We send them views of each of the coronary arteries, and we also send them specific views that are labeled for any pathology that's present. We also send them the volume-rendered images because patients always want to see the colored images of their heart.

FISHMAN: Does anyone else do anything differently in their practice?

STEPHAN ACHENBACH, MD: We basically just send our referring physicians a written report, and not specific images, because we find that they really want a summary in two or three sentences. They're not so keen on looking at the images, but we do include 3D-rendered images that we send directly to the patient, because, as you said, that's what the patient asks for. It is exactly the same situation, the physicians read the scans interactively, and the technician does the 3D rendering. The 3D images are only for the patient.

FISHMAN: There is something we try to do, which can be the best thing we do, but can also be the most painful. Do you routinely review images with the patients?

ACHENBACH: We often do, yes. It's problematic because the important findings are in the 2-dimensional images that the patients do not understand, but the patient still appreciates that the physician takes some time to look at the images with them. So we very often do that, if we think that the patient has the intellectual capacity to follow what we're telling them. We especially try to convince a patient who has been reluctant to go to the cath lab when we have a finding that we think needs catheterization. In that case, we show the patient the images, and no matter whether or not he or she understands what's going on, the fact that the physician sits down with review the data of the heart makes a patient realize that it's serious enough to undergo catheterization.

SAMUEL WANN, MD, MACC: We don't routinely send images to our referring physicians. You would think in a private practice we would be more interested

in doing that. But, actually, I would prefer to dampen the enthusiasm. I feel it's sort of sleight of hand to send these derived images out to referring physicians, since I don't make my diagnosis from those snapshots. It seems disingenuous if these illustrations are represented as the data from which the diagnosis was made. I do show these derived images to patients and referring physicians sometimes, but with the caveat that this is not where the diagnosis came from. The other reason I haven't bothered to send these snapshot images to the referring physicians is that it is very time-consuming, and, in a private practice setting, time is very important. I do look at all the images much like you all do, but I don't make those advertising brochures for referring physicians.

FISHMAN: What do you document? In a sense, you have infinite images, but you have to document something for the medical records. Do you save certain snapshots?

WANN: We definitely save the phases on an optical disk, and you can reconstruct the images. We don't save the raw data, of course, but we do save all the phases, and we do not save any snapshots. Really, we should talk about that. They're not diagnostic images, so why would I save nondiagnostic documentation? If I were to go to court, I wouldn't want to defend my diagnosis based on those snapshots.

ACHENBACH: You can always re-reconstruct those.

WANN: We do save the phases and reconstruct the data. We can look at the actual slices, and make the 3-dimensional pictures. I'm willing to change my mind, I'm just telling you what we do.

FISHMAN: We'll tell you in a few minutes why you have to change your mind. Chip, what do you think?

CHIP GILKESON, MD: We do a couple of things. We use the PACS; certainly it is very helpful, having access with our PACS. Then we usually have representative MIPs, not a snapshot. An MIP is probably the most helpful, certainly rendering gives you very nice images, but representative MIPs of the significant stenosis or finding goes to the

PACS. Now our physicians really do understand that there is always going to be representative pictures of the pathology on the PACS. Then, with our technologist, we also look at the phase that most accurately shows the pathology. We do send one collection of that phase to the PACS. So, usually, all the phases are put on a workstation temporarily. But in terms of dissemination to the PACS, we choose one optimal phase.

MATTHEW BUDOFF, MD: You have to start from the technician's side of things. They also do the calcium scoring, and the wall motion assessment, at least the measurement of the ejection fraction. We obviously look at the data. From a physician's standpoint, we've always sent out images. We started doing this 10 years ago. It started from a different perspective, as more of an advertising campaign. But now a lot of our physicians are very savvy to interpreting the studies. They really like to see at least some representative images, maybe a MIP or images we used to make the diagnosis, to see how long the stenosis is, if it involves branches, things that we might not go into enough depth of describing. Its like how they might want to review the cath images at some point. I give them a few selective images they might be able to use in their diagnostic evaluation if they're going to catheterize or perform an intervention on the patient; sometimes they like to see those pictures.

JAMES K. MIN, MD: We don't send images out to our referring physicians. We just haven't gotten around to it, as it takes a lot of time. We don't ask the technologist to do any postprocessing for us other than to retroreconstruct different phases. Then we read it and report it. We have a Web-based reporting system, so we finalize the report, and then we e-fax the report off.

WANN: Having been in imaging for a long time, my perspective is that we don't send out snapshots of echocardiograms. All the cardiologists who have access to the workstation can come to look at the raw data. We don't send out snapshots of the cath film, although I understand some people do. Virtually all of our cardiologists are very capable of coming in to look at the original cath data. Similarly, on the nuclear studies, we record the standard data set, and we do send that out, but we don't send out a snapshot of the pathology, if you will, from which the diagnosis was made. So we have a long tradition of our cardiologists coming in and looking at the raw data, and I'm trying to encourage them to come and look at the full CT data set, as well.

It would be interesting to discuss, but I think the majority of cardiologists in clinical practice will eventually interpret their own CT angiograms, and to lead them to believe that some derivative 3-dimensional image that a technologist presents to them is the way a diagnosis I made, I think, is getting off on the wrong foot. So, they really need to get used to looking at the entire data set themselves, and the workstations aren't that complicated. It will all eventually be available on the PACS. You can do it in the office, or do it at home. I think the future is not to restrict access to data, but to make it easier to look at the full data set.

ACHENBACH: I would completely agree. If you look at the interventional cardiologists' perspective, I think what we'll have very soon is that in the cath lab you can actually pull up the CT data set of a given patient, and you look at what the anatomy of a certain lesion is like. This would not be routine, but if you have a lesion that is very close to an ostium or bifurcation, the additional 3D information can actually help you make decisions about what kind of treatment to choose. For example, in a bifurcation lesion, I think that's what will happen, since cardiologists are used to looking at imaging data. Interventionalists will have access to these data sets in the cath lab so they can just pull up the original data set, and move up and down through the data set.

WANN: Even our surgeons are becoming big fans of this. They've long looked at echo in the operating room, they pull up the original cath films in the operating room, and they've started to look at the CTs in the operating room.

FISHMAN: I'm not disagreeing with anything you've said, but there are two different things involved. We've been doing 3D for 20 years, so we have a long tradition in both cardiac and noncardiac imaging. Everything is done by the physician, which is basically what everyone is saying here. So we totally agree on that. But we do create select images that we do send to the PACS, but we also print the images on color film and deliver them to the referring physicians the next day. There are several things that this does. It doesn't eliminate the fact that people can go look at the data themselves. With a thin client, with 3D on PACS, availability is only going to increase over time, so that's kind of simple. But I think that one of the things it does is it provides information to the many physicians who don't have access. We often deal with internists. People want that information when they're outside the system.

The other thing is that one of the challenges in imaging for all of us involved on a daily basis is that we have a hard enough time keeping up with change. If you're a family physician, an internist, or you're in an affiliated field, you don't really know what's going on in imaging on this level. So in providing the images, it's not just the PR, it's really a teaching process. When we can get that information in someone's hands, they can see what our capabilities are. One of the things I've often found is that you know what your capabilities are, but the referring physician may not really know what your capabilities are. After seeing Jill's images, I think we all would agree, that one image tells a story of what you can do.

ACHENBACH: That's only when the data set is of perfect image quality. There are data sets for which the image quality is not so good, but you can still make a good reading out of it.

FISHMAN: We only show good images now.

ACHENBACH: If you send out a data set that's difficult to interpret, it can convey the wrong message that it doesn't work well.

FISHMAN: I don't think we send out the data set, as much as we send on representative images.

We all need to recognize, as you've written in many of your articles, that it is also important that the referring physicians understand what the limitations of the technology are, and what your success can be. We all would agree we're not 100% successful, but from a radiology perspective, one of the challenges that we have always faced is the discordance between what we do and what people see, and that's really a challenge. We see the same thing with surgery and with many of the specialties. It's just that everybody is so busy these days. In some ways, I think the referring physicians really appreciate at least getting something on their desktop, because then at least they can start from there. They can go do more, as you said, but at least it's a baseline.

JACOBS: I just want to clarify that we do send MIP images and we send labeled axial images, so it is truly representative of images that we've used for diagnosis. But the other reason our referring clinicians like it is that they're often in consultation with the patients in their office. They can pull out the images and can show the patients the images and see them labeled. We've heard many of our referrers say that it has a huge impact on patients to be able to actually see what's going on in their vessels, and it helps them stay on a drug regimen, if it's prescribed for them. It helps them agree to go on and have therapy or catheterization when they actually can see the amount of plaque or the pathology that they have in their vessels.

FISHMAN: There have been several articles published that have actually documented those things.

ACHENBACH: I think that this is a potential use for the wonderful software tools that have been developed that automatically create extracted vessel contours and automatic reconstructions. Many people have the capabilities to do this automatically on their workstations, but they don't use it because it's just faster to just go up and down the axial image data set. If you want to create some images to send out, then these tools can be very, very useful. It's probably what will be one of the major applications for these automatic software tools—to automatically create images that can be sent out.

WANN: I use all these pictures and educate my patients, too, and my referring doctors like it. I'm quite concerned when I have patients come in who have had CT angiograms, and they have all this documentation. As someone said, it's not what you don't know that is the problem, it's what you know that's just not so is the problem. I think there is over-reliance on the numbers, particularly the precise percent stenosis. I see very detailed reports coming in that say "52% stenosis" or "20%" and include arrows drawn for things that are just very difficult for me to understand. When I look at the raw data, I have a lot of trouble being that precise, that definite, and that concrete, even if I'm showing you a picture. I lay awake at night worrying about some of the studies I read in terms of making clinical decisions, and if you send a picture to a physician who is less involved with this very discrete, concrete description of the thing, and I'm concerned that he will believe me. I think there needs to be a lot of skepticism going on here in clinical decision making based on CT. I don't think it is good to send out these nice reports that are very dogmatic.

FISHMAN: That brings us to another topic; something that has not been addressed in detail in literature is accuracy. Almost every article written is based on a single reader. Typically, classic articles determining accuracy have 3 readers. So, that's an issue in terms of software; no one has compared one vendor's software to the others. So we do not know the accuracy of software. There is an article on virtual colonoscopy showing that the accuracy varied by 30%, depending on which system you use. I have no doubt that it's probably going to be the same thing in cardiac imaging. Then there is, of course, the individual user experience. Even in this group, I'm sure that if we looked at the same cardiac imaging, the results may not be the same.

WANN: We don't have good data to show that our CT angiographic readings are actually not only accurate, but change practice, and are not just additive information. So we're being held to a very high standard now.

ACHENBACH: In fact, if you read them very carefully, some publications give accuracies for different readers. Just the last one that you cited, Nikolaou, I remember, I believe, that compares reader number one and reader number two, and the accuracies are approximately 86% for one reader and 79% for the other. There was a very early article by Nieman, which also had two readers with very different accuracies, approximately 86% and 81%. So there is no question that it really does depend on the reader.

FISHMAN: We did an article on 4-slice CT with 5 readers looking at stenoses that were computer-generated. With rendering techniques, the variation of accuracy ranges from 95% to 16%—and this is just in computer data. Again, it's based on experience using tools, but I think that's one of the challenges, which is really not addressed.

ACHENBACH: We cannot hold it only against CT because if you have two interventional cardiologists looking at the same invasive angiogram, you'll come up with very different opinions.

FISHMAN: The same thing is true elsewhere. When the articles came out on pulmonary embolism, the gold standard was pulmonary catheterization, which was basically assumed to be 100% accurate. But when you looked more closely through the literature, there was actually 30% interobserver variability. In that case, how could the study be 100% accurate?

But I think what would be very nice in terms of radiology would be to create studies so that people really do know what the variability is. We need to know about potential variability and reproducibility, and which studies are most prone to error. Perhaps your society can push those types of things, and we can push them from our side.

I would guess that when you have extensive calcification, those are the studies that are most prone to error. The studies that are not done perfectly technically, those would be more prone to variability.

WANN: Well, the other question is what your reference standard should be—it may not be an interarterial angiogram. I like to say that CT angiography is not a picture of contrast material, which is what we get in the cath lab, but, rather, a CTA is a picture of the vessel wall. It's certainly related to stenosis, but it's also related to the plaque, which is better seen by intercardiac ultrasound. If you're talking percent stenosis, we're really talking about obstruction of flow, which is better done with a flow wire, and we really need to measure gradients and flow reductions if we're trying to relieve ischemia with our therapeutic intervention. I think we must get beyond just looking at images and equivalence, and look at how we actually use that information, and use it better to plan therapy. If we're trying to improve flow, we better have reduced flow to start with, and to compare the percent stenosis on a CT angiogram to a flow wire makes more sense to me than trying to compare it to another imperfect diagnostic technique.