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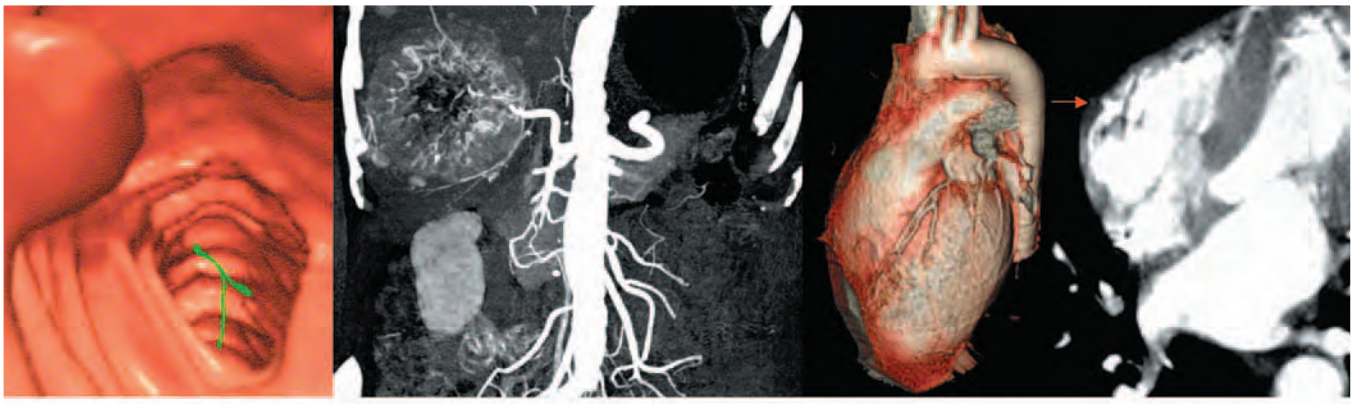
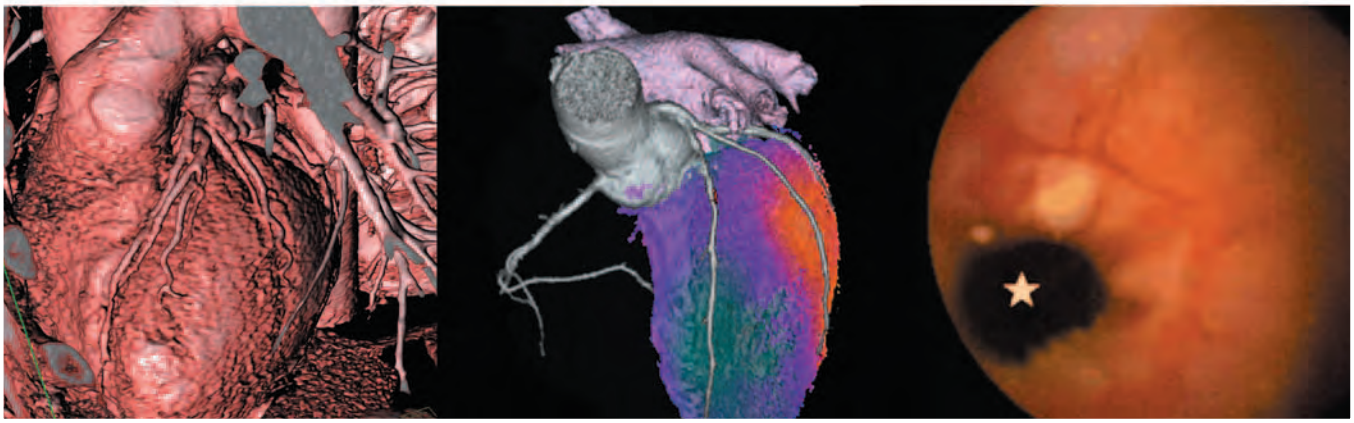


HOT TOPICS IN CT

Six Clinical Presentations and Open-Forum Discussions



Moderated by Elliot K. Fishman, MD
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CME Category 1 Continuing Medical Education

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Target Audience

This activity is intended for radiologists.

Learning Objectives

At the conclusion of this program, the reader should be able to:

- Recognize the current state of the art of CT imaging, including its clinical applications in a number of anatomic regions;
- Determine when and why to use CT;
- Distinguish the relevant issues related to the selection and use of contrast media in CT and CT angiographic procedures; and
- Recall pertinent critera for accurate CT studies, including contrast administration, image acquisition, postprocessing techniques, and scan interpretation.

Activity Description

Estimated time for completion: 6 hours

Date of release: November 1, 2007

Expiration date: November 1, 2008

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Introduction

In May 2007, I served as the moderator of the eighth in a series of CT Forums. The first seven meetings addressed various aspects of the use of intravenous contrast in computed tomographic angiography (CTA) applications. The proceedings of each of these Forums have been published as special supplements to *Applied Radiology*, in print, online, or both. This most recent Forum addressed current "Hot Topics in CT" with a focus on cardiac and gastrointestinal (GI) applications.

The tremendous advancements in CT technology (including scanner hardware, workstations, and postprocessing software) have led to dramatic expansions of the use of CT imaging in clinical applications. With the advent of 64-slice CT, CT imaging of the heart is now possible in ways that were impossible just a few years ago. The recent publication of the results of the ACRIN study have validated the use of CT colonography and can be expected to quickly expand its use as a screening tool throughout the United States.

The goals of the May Forum, and of this supplement, are to:

- Review the current state of the art of CT imaging, especially its clinical applications in cardiac and gastrointestinal imaging;
- Provide key information on the selection and use of contrast media in multislice cardiac CT procedures;
- Review when and why to use CT, particularly with postprocessing techniques;
- Provide "how-to" information for performing optimal CT studies, including contrast administration, image acquisition, and scan interpretation; and
- Provide a better understanding of the challenges of offering advanced CT studies in emerging clinical applications.

This supplement comprises an impressive array of review articles by a distinguished panel of experts. I presented an overview on the state-of-the-art "hot topics" in CT; the rest of the panel included:

- DeAnn Haas (GE Healthcare, Waukesha, WI)
  Current status of CT technology
- James P. Earls, MD (Fairfax Radiological Consultants, Fairfax, VA)
  New developments in cardiac gating
- Charles S. White, MD (University of Maryland, Baltimore, MD)
  Triple rule-out CT in the emergency department
- Michael E. Zalis, MD (Massachusetts General Hospital, Boston, MA)
  CT colonography: Toward a computer-aided, noncathartic examination
- Michael P. Federle, MD (Univerisity of Pittsburgh Medical Center, Pittsburgh, PA)
  CT of the small intestine: Enterography and angiography

I would like to thank GE Healthcare for sponsoring the CT Forum series and for providing an educational grant in support of this publication, Anderson Publishing for producing this special supplement, and the Forum participants for preparing a comprehensive overview of current and future CT applications.

Elliot K. Fishman, MD
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Hot topics in CT

Many new clinical applications are possible with 64-slice CT. Enjoying the full benefits of this technology requires taking the next step in postprocessing and workflow management.

Elliot K. Fishman, MD

Dr. Fishman is a Professor of Radiology and Oncology, and the Director of Diagnostic Radiology and Body CT, Johns Hopkins Hospital, Baltimore, MD.

Computed tomography (CT) is changing rapidly, and its newest capabilities are being adopted with impressive speed. Enthusiasm for 64-slice CT technology has been particularly strong. Informal surveys of general radiologists attending medical meetings suggest that, today, roughly 70% to 80% of radiology practices have a 64-slice scanner. The importance of this observation lies in the many applications that are possible with advanced CT technology. This supplement will focus on 2 specific types: cardiac and gastrointestinal (GI) applications.

State-of-the-art CT—particularly cardiac and some vascular applications—demands that scanners have three major features:

- High spatial resolution, typically <0.4 mm;
- High temporal resolution, typically 150 to 180 msec, but as low as 83 msec with dual-source scanners; and
- Isotropic data sets, which enable image acquisition in a single plane but display in any plane or perspective, without sacrificing resolution.

It is also critical that we have the ability to time the administration of contrast material in a way that optimizes its delivery with data acquisition. For 30 years we have struggled to tightly couple the timing of contrast administration and data acquisition, and now, with the 64-slice scanner, it can be accomplished routinely.

Contrast

There are several common themes in the review articles featured in this supplement. One key concept is the importance of careful study design, including patient preparation, contrast selection, and the study protocol. Study protocols are of particular interest. Practicing radiologists want to know how to do studies, how to avoid common pitfalls, and how to benefit from the "pearls" that more experienced users have to offer.

A successful study relies on the appropriate selection and delivery of contrast material. For GI studies, the oral contrast agent may be neutral, such as water or VoLumen (E-Z-EM, Inc., Lake Success, NY), or positive, such as oral Omnipaque (GE Healthcare, Princeton, NJ) which is prepared by mixing 100 mL Omnipaque 350 mgI/mL in 1 gallon of water.

At Johns Hopkins Hospital, we tend to use water or a neutral contrast agent for most GI applications, as this enables both optimal visualization of small vessels and enhancement of the bowel (Figure 1). Positive contrast material works well for some applications—for example, CT examination of the stomach. In our experience, the Omnipaque-water solution described above provides an attenuation value of approximately 200 to 250 HU.

The selection and administration of intravenous (IV) contrast material are also critical factors in determining the success of the study and in ensuring patient safety. The radiologist must decide between low-osmolar and isoosmolar contrast agents as well as among the various concentrations available for each agent.

In 2006, Johnson and Fishman[1] reviewed a wide range of studies published over 3 years in *Radiology*, *The American Journal of Roentgenology*, and *The Journal of Computer Assisted Tomography*, with the goal of evaluating how contrast concentration affects multidetector CT of the body. Most of the CT angiography studies compared higher concentrations (350 to 400 mgI/mL) with 300 mgI/mL contrast material. There was no evidence that showed a significant difference in diagnostic efficacy with higher concentrations, particularly for studies of hypervascular hepatocellular carcinoma or pancreatic cancer. In fact, several of the studies showed that results were poorer with concentrations >350 mgI/mL. At Johns Hopkins, we typically select contrast medium with a concentration of 320 to 350 mgI/mL.

Concerns about contrast-induced nephrotoxicity (CIN) also affect the selection of contrast material. This is particularly important, given our aging population and the increasing volume of CT diagnostic examinations. There are many steps that can minimize the risk of CIN, including hydration, withdrawal of nephrotoxic drugs, the use of acetylcysteine, and minimization of contrast volume. A substantial advantage of 64-slice CT is that, typically, contrast volumes total 100 to 120 mL, sometimes even less,

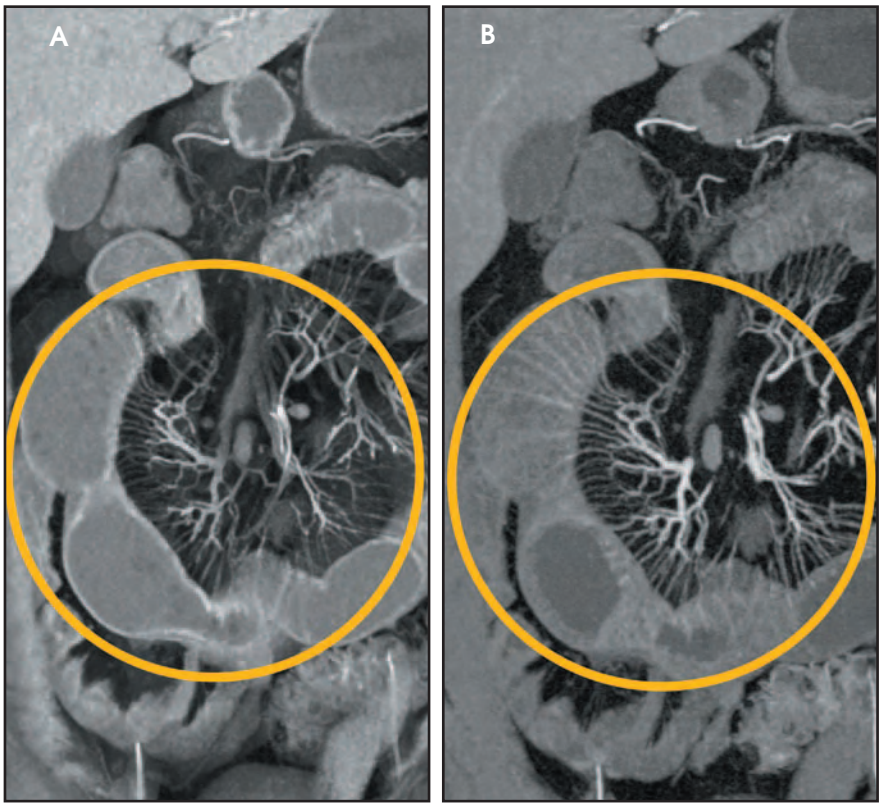

FIGURE 1. *A patient with Crohn's disease is shown with (A) a volume-rendered technique and (B) a maximum-intensity projection image. The use of water enables optimal visualization of the small vessels and increased enhancement of the bowel (circles).*

as compared with a typical volume of 150 mL with 4- or 16-slice CT.

The selection of contrast material is also critical. The published literature for the last 15 years has shown that osmolality plays a significant role in CIN. In virtually every study, the lower the osmolality, the lower the risk of CIN.[2-5]

The Nephrotoxicity in High-Risk Patients Study of Iso-Osmolar and Low-Osmolar Non-Ionic Contrast Media Study (NEPHRIC) provides important information on the role of osmolality in CIN.[6] The study involved 129 patients with diabetes and serum creatinine levels of 1.5 to 3.5 mg/dL who underwent coronary or aortofemoral angiography at 17 centers in Denmark, France, Germany, Spain, and Sweden. The patients were randomly assigned to receive iodixanol, an iso-osmolar nonionic contrast agent, or iohexol, a low-osmolar nonionic contrast agent. The primary endpoint was the peak increase from baseline in the creatinine concentration during the 3 days after angiography. Other endpoints were an increase in the creatinine concentration of ≥0.5 mg/dL, an increase of ≥1.0 mg/dL, and a change in the creatinine concentration from day 0 to day 7.

Regardless of the endpoint, Aspelin et al[6] found a significantly lower incidence of CIN with iso-osmolar contrast media. For example, whereas the mean increase in serum creatinine by day 3 was 0.55 mg/dL with iohexol, it was just 0.13 mg/dL with iodixanol ($P = 0.001$). Therefore, many practices, including our own, choose to use an iso-osmolar contrast agent when scanning high-risk patients—for example, those with diabetes, a history of renal disease, or those who are critically ill.

A meta-analysis by McCullough et al[7] supports this practice. Pooled data from 2727 patients indicated that the use of the iso-osmolar contrast agent iodixanol was associated with smaller increases in serum creatinine levels and in lower rates of CIN when compared with low-osmolar contrast media, especially in patients with chronic renal disease or a combination of chronic renal disease and diabetes.

Advancing technology

Scanner technology continues to advance at a rapid pace. Spiral scanners have gone from having a single detector in 1989 to 64-detector rows today. Perhaps someday we will have scanners with 512-detector rows. The introduction of dual-source scanners raises a question as to how many X-ray tubes are enough. Detector size is also under scrutiny, as researchers attempt to determine whether it is necessary to have a detector that can cover the entire heart or the entire brain in a single gantry rotation. Finally, at 33 msec, rotation speed is excellent on today's scanners. However, if the gantry could rotate 4 times per second, rotation speed would be just 20 to 25 msec. The question is, is such an improvement needed?

Researchers pursue technologic advances not for technology's sake, but rather, for the applications they make possible. These new applications are driving CT today. Across the country, the average annual growth rate for body CT is 10% to 15%, for example. Cardiac CT, which is in its infancy, has the potential to significantly change not only the volume of CT scanning but its very direction. Perfusion imaging—in particular, the ability to detect tumor neovascularity—is another important emerging application of 64-slice CT technology.

Perfusion imaging enables us to not just understand patterns of contrast enhancement, but to use those patterns to assist in treatment decisions. In the case of liver lesions, for example, we have long known about differences in lesion appearance on early- and late-phase imaging. Such information is routinely used in the differentiation of benign and malignant tumors and in the assessment of the infiltration and extent of a lesion. Now it is also possible to assess the neovascularity of a lesion (Figure 2). With the availability of new antiangiogenesis drugs, assessment of neovascularity

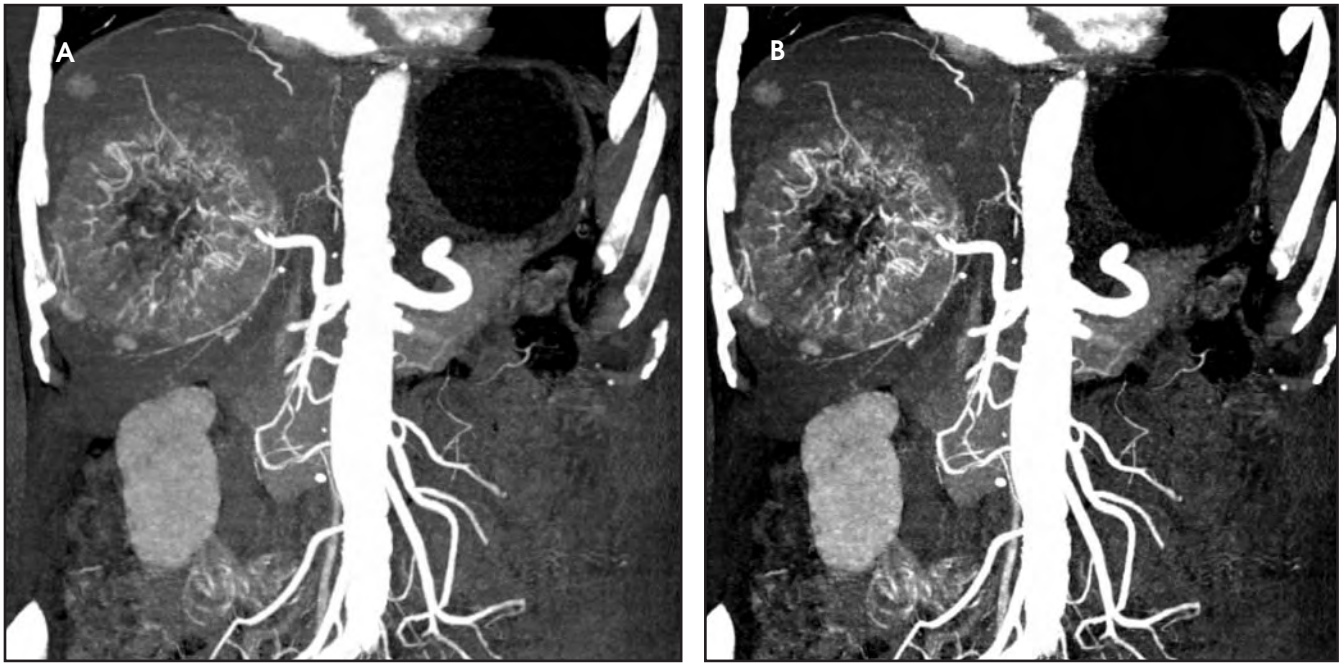

FIGURE 2. *A patient with a hypervascular hepatoma. (A and B) Three-dimensional imaging shows extensive neovascularity and satellite lesions.*

becomes critical and can play an important role in selecting optimal treatment for tumors of the liver and other organs.

Workflow

In the past, axial CT images were generated by a technologist and reviewed by a radiologist, who dictated a report and moved on to the next study. Today, a great deal of work and time goes into creating 3-dimensional (3D) CT images. Data sets that comprise thousands of slices today will soon comprise 5000 slices or more. As a result, one of the biggest issues in CT today is not the scan acquisition itself, but everything that comes after.

The ability to successfully manage workflow is a critical factor differentiating radiology groups that are successful in implementing volume CT imaging from those that are unsuccessful, whether in a small or large hospital, a clinic, or an outpatient center. Many groups that have 64-slice scanners today still operate as they did with a 4-slice scanner in how they acquire data, use data, and think about data.

Today's CT scans create thousands of thin slices, yet many radiologists are still looking at thick slices. Many look only at axial images, rather than taking advantage of the information contained in multiplanar reformats and other forms of 3D imaging. Even those who have embraced 3D imaging must decide whether they will review only preselected 3D images prepared by a technologist or work interactively with the data set. The location for 3D postprocessing is an issue in many institutions. Will it be done in the reading room, at the scanner, or even in the operating room? The role of referring physicians in this process must also be re-evaluated. Will they consult with the radiologist as the 3D images are prepared, or will they be passive users at the end of the process?

In an article in *Radiology*, Boone[8] coined the term "extreme" multidetector CT, drawing the comparison to extreme sports. In the case of imaging technology, "extreme" means that 64-slice CT has the potential to revolutionize cross-sectional imaging but also demands substantial infrastructure improvements in order to maximum its utility.

It is important to analyze workflow in the CT department, identify common bottlenecks, consider the best practices used in CT departments across the country, and evaluate the innovations that may be necessary for CT practices to successfully evolve over the next 3 to 5 years.

Postprocessing

Critical improvements are being made in postprocessing tools. For many years, the same 3D postprocessing techniques were used for every application. Over the last 12 to 18 months, we have seen the introduction of postprocessing tools designed for specific problems. These tools make specific tasks easier, faster, and more accurate, and provide new information not previously available.

Task-specific postprocessing tools include those used for bone editing, vascular segmentation, coronary artery assessment, vascular stent placement, and real-time rendering. In cardiac CT, for example, advanced postprocessing tools enable the creation of gray-scale 3D maps from multiple perspectives, color volume renderings, and curved planar reconstructions (CPRs). These are all critical tools that are used on a daily basis.

When image data are displayed as a CPR, the computer is able to select the center line through the vessel, track the vessel, separate it from surrounding tissue, and display it through any plane or perspective. Computer-assisted tracking enables the vessel to be laid out and examined much more carefully than would otherwise be possible.

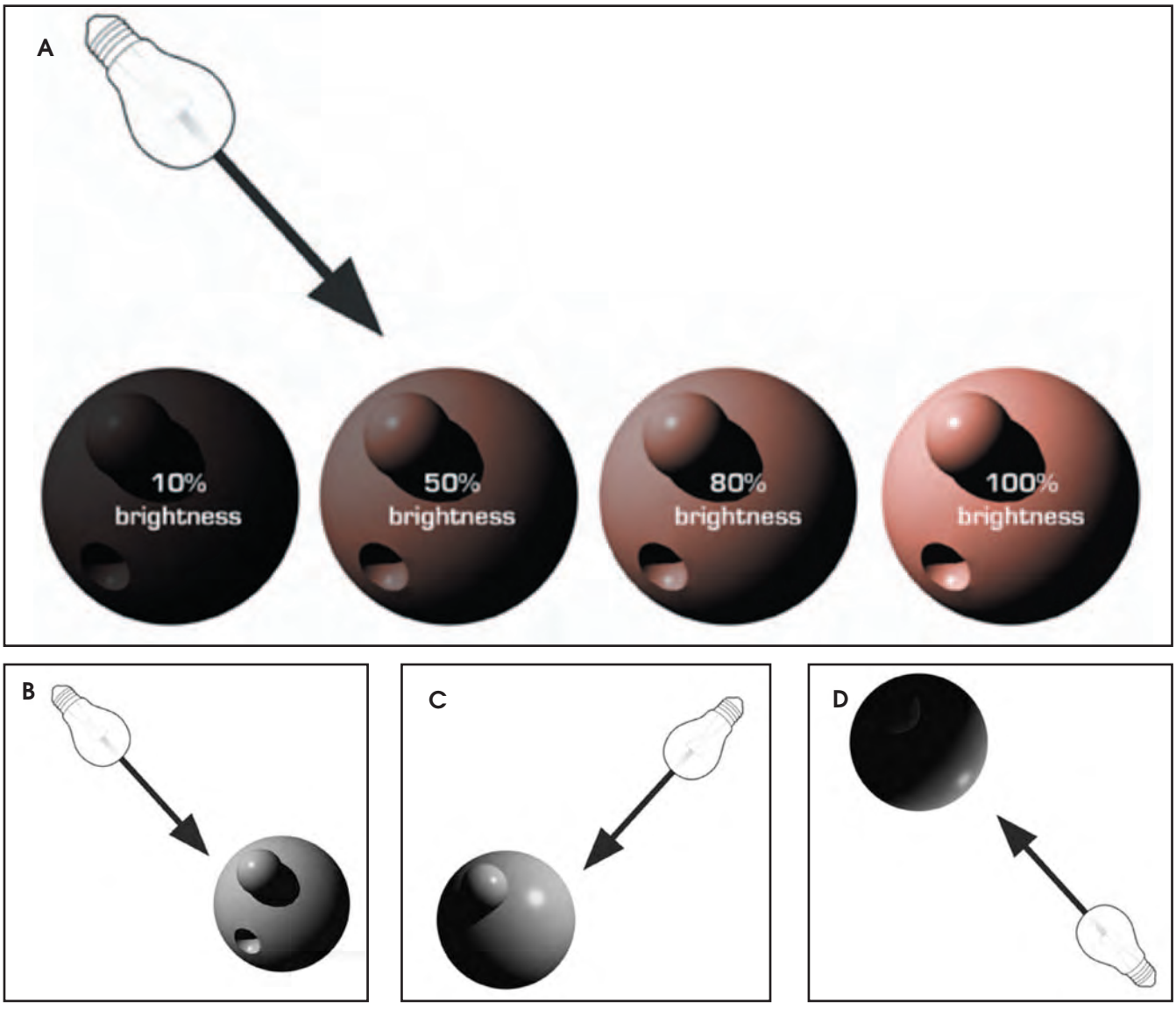

FIGURE 3. *(A) In this model, changes in the brightness and the orientation of the light source markedly change the visualization of both the large and small balls and the divot in the large ball. (B through D) These images show the changes with the orientation of the light source: (B) Upper right light source, (C) upper left light source, and (D) lower left light source.*

Such close examination not only makes it possible to identify calcified and noncalcified plaque and evaluate the patency of stents, it also holds promise for improved quantification of luminal compromise. Over time, postprocessing technology must become much more accurate in generating a specific degree of stenosis at selected points along a vessel. It is hoped that this will reduce some of the variation in study interpretation between individual reviewers.

At Johns Hopkins, we believe that postprocessing is best done by the radiologist at the time of interpretation. We prefer a radiologist-driven model because we see no division between the creation of 3D images and the interpretation of 3D images. Instead, we see it as a single step. If a 3D technologist does the postprocessing, the radiologist will see only what the technologist saw, will not see what the technologist did not see, and may see things that are not really there. In any data set, it is possible to "create" information that doesn't exist simply through the choices made in postprocessing.

As 3D techniques become more prevalent, it is important to focus on quality, including image accuracy and display technology. Lighting is a key parameter that often is not fully appreciated. The model in Figure 3 shows how a relatively small change in lighting influences what the radiologist sees at the workstation.

Changes in the lighting model can markedly influence clinical images as well. As the lighting changes, image texture and definition change markedly, in both color- and gray-scale. As a result, variations in lighting can be used to better visualize arteries throughout the body. All of the information is contained in the data set; changes in the lighting model enable it to be seen.

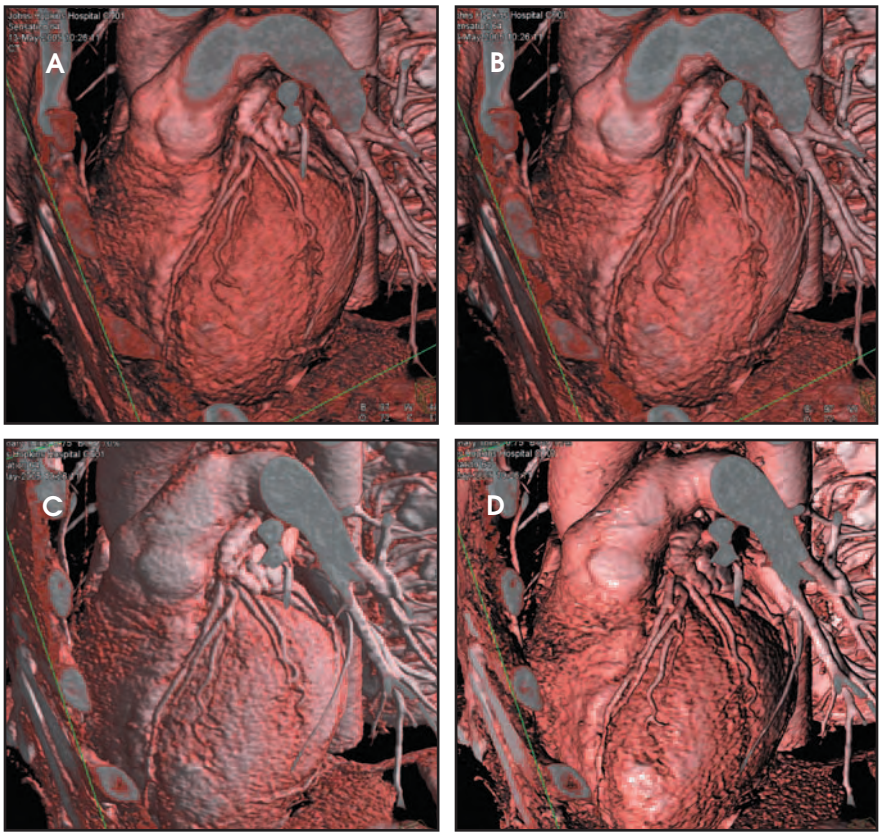

FIGURE 4. *The influence of lighting changes on the visualization of the coronary arteries. (A through D) Each of these images of the heart is derived from the same data set using the same volume-rendering parameters. The only difference between the images is a change in the lighting source.*

The same concept applies to the heart. Analysis of the coronary arteries is very dependent on how those vessels are visualized. Figure 4 shows several volume renderings of the heart. All are derived from the same data set using the same volume-rendering parameters. The only difference between the images is a change in the lighting source.

Interacting with the volume data set enables the radiologist to have full control of the information contained in thousands of slices. It then becomes possible to go beyond 3D imaging to 4D imaging and to examine the heart in motion. CT nicely depicts valvular function from many planes and perspectives. It is adept at depicting left ventricular function as well.

Quantitative measurements of cardiac function are being demanded by referring physicians and are, therefore, critical to the future of cardiac CT. All vendors now offer tools for doing quantitative measurements of ejection fraction and other functional parameters. These tools are becoming simpler to use and allow radiologists the opportunity to interact very closely with referring physicians in an era in which electronic imaging has markedly reduced the opportunity for personal consultations.

Client-server model

Over the years, certain limitations have impeded implementation of 3D imaging in clinical practice. These include limited system capabilities, limited system reliability, and a lack of user training. Even today, the cost of workstations and their availability in limited numbers at fixed locations represent hurdles to access and widespread use.

As a result, we are beginning to see implementation of the client-server model, which enables multiple users to access powerful workstations from many locations at the same time. This model has tremendous impact, as it eliminates the need to do postprocessing in the 3D lab, instead making postprocessing available to everyone everywhere. In fact, at Johns Hopkins, users are not just radiologists but also referring physicians, treating physicians, fellows, residents, and medical students.

Postprocessing is not limited by location either. Remote connectivity is excellent by cable modem or digital subscriber line (DSL). Virtual private networks (VPNs) ensure security and provide access across the city or the nation. We often hold conferences in real-time using a client-server workstation. Patient management decisions are made at such conferences after analysis of the clinical images.

Having all of the tools for specialized image analysis available at each reading station markedly improves efficiency. This model also encourages development of new postprocessing tools. Cardiac imaging may be among the hottest applications of advanced CT, but oncology accounts for approximately two thirds of the CT volume in many institutions. In oncology patients, CT is often performed to assess the growth or regression of tumors. Manual interpretation can be both time-consuming and inaccurate, but with appropriate technology at the reading station, computers can automatically evaluate tumor volumes. In addition, computer-aided diagnostic systems can be used to improve the detection of lesions.

There are challenges associated with a client-server model. We now have >400 sites of 3D CT data postprocessing at Johns Hopkins. Reading stations are used not just in radiology but in surgery, oncology, and gynecology, just to name a few locations. Training becomes an enormous issue, determining who needs to be trained and who will do the training.

Some radiologists may also develop "availability anxiety." In the past, radiology maintained a film library and owned and controlled the films. Now, many different people have access to a great deal of information. Does that access

challenge or even eliminate the radiologist's central role in image management?

In many institutions, a dual system of both classic and client-server workstations will be used to meet the needs of radiologists and referring physicians. Implied in this concept is the seamless integration of picture archiving and communications systems, resulting in a single virtual system with all the necessary postprocessing capabilities at the user's fingertips.

Conclusion

Today the hottest trends in CT involve more than just clinical applications. Workflow is critically important, and postprocessing is constantly evolving. To take full advantage of the capabilities of 64-slice CT, it is necessary to look at the whole process over the entire enterprise, and determine how to evolve to meet these new challenges.

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Discussion

ELLIOT K. FISHMAN MD: Everyone in practice today is very busy; volumes are very high and staffing is tight. The number of relative value units (RVUs) per physician is continuing to increase. What do you think is the biggest challenge people face in being able to use 64-slice CT in practice? What are the barriers? DeAnn, you deal with applications and training. What do you see as the issues from your perspective?

DEANN HAAS: We've visited sites with multiple scanners, and I believe the biggest issue is that they have a variety of scanners in the practice. So a lot of physicians have told us that they want all their protocols and their reading techniques to be similar. So if the 4-slice is the lowest set scanner, they set their protocols up to the 4-slice, which means they actually run their 64-slice scanner like a 4-slice. This way, from scanner A to scanner B to scanner C, the images will all come out the same.

When you explain to them, "You should move your vascular and your cardiac scans to the 64-slice, and your heads to the 4-slice in the biopsy," they say that that's well and good in practice but that, in reality, it's too hard for them to manage their patients throughout the different scanners. So that's really where the challenge is. They believe that the 64-slice scanners give you excellent image quality. But they want a simplified read so that they can read all the patients coming through their practice.

FISHMAN: So basically, you're saying it's hopeless!

HAAS: I don't think it's hopeless. In the big academic centers, they are using the technology where the technology is needed. But in the smaller practices, there are not as many subspecialized physicians, and they try to keep the protocols more similar. This way, they're not finding more information on one scanner, and less on another.

FISHMAN: But your suggestion seems to be a likely solution. I think every practice, big or small, has multiple scanners. That's just the way it is. The critical message to people is, as you said, to triage your work to different scanners. You should do certain things on the 64-slice, but use your 4-slice for the biopsies or abscess drainages.

HAAS: Exactly.

FISHMAN: Jay, what do you think the challenges are?

JAMES P. EARLS, MD: I think the challenge is in implementing some of the more sophisticated processing or scanning. People coming out of fellowships now are primarily good at reading studies in the axial format. But they aren't necessarily ready to step up to the plate and start doing sophisticated 3D processing, or preparing individual protocols for unusual exams. They just don't have the experience to be able to do that.

So, this lack of experience is combined with an environment in which everybody is very busy, and there are lots of cases to read every day. As you say, RVU per radiologist is going up every year. Newer radiologists just don't have the time or opportunity to do these advanced techniques, which is why they default to functioning in a 4-slice world again. Unless you have one person who wants to take the time—in private practice that means extra time in their days to actually set up the protocols and spend the time doing it—it won't happen the way that ideally it should happen.

FISHMAN: You are in a large private practice group. How do you avoid the problem?

EARLS: We are a large group with 72 radiologists that functions with a subspecialization model; this includes an 18-member body imaging section. In that section, we have subspecialists who are physician champions of specific technologies and we give them the time to develop it. We're uniquely situated because we are such a large group, and we're able to do that. I think that would be much more difficult to do in smaller groups with a more general practice model.

FISHMAN: Mike, what do you do in Pittsburgh?

MICHAEL P. FEDERLE, MD: We triage, according to the type of study, which scanners are best equipped to do that. We are obviously subspecialized in a large academic practice. So, we also have champions of particular techniques. We have people who are uniquely good at cardiac imaging and CT angiography,

and so forth. I would echo what Jay said about some of the challenges of people getting trained to do the sophisticated 3D workstation applications. We still have relatively few people in our practice who are very, very good at it, good enough to do the cardiac studies. I think those studies are probably the most challenging.

We have a lot of people who are capable of doing multiplanar and 3D work to evaluate vessel anatomy for transplant candidates or donors or recipients, which is a big part of our practice. One thing I think we should talk about at some point in the day is whether or not 3D should be done routinely, particularly since third-party payers are, in fact, to some extent discouraging it. I think there have been abuses in the past, with people putting in extra bills for having done a 3D reconstruction when it was considered not relevant to the patient's condition.

We actually have been challenged on this in Pittsburgh by our third-party payers, and they have pretty much let us know they're not going to pay for a 3D or multiplanar workstation charge unless it was specifically requested by the referring physician. So we've had to work with our clinicians to inform them that they are going to have to order it separately or specifically, obviously for cardiac work, for abdominal aortic aneurisms, and for other things for which they are specifically interested in that aspect of the display and interpretation. In fact, with some of our third-party payers, they actually have to put in for prospective approval for that. So that's an issue that is a practical aspect of putting these techniques into practice.

FISHMAN: We have the same issue in Maryland. A physician has to request the 3D. So you're right, a lot of it involves training the physicians. Also, within a practice, radiologists can't write 50 separate protocols. So we designed a pancreatic protocol, which is defined as dual-phase imaging with 3D angiographic mapping. So we've been able to work with insurance companies. But you're right, you can't just randomly say, "I want to do a multiplanar image;" that's what happened with neuroimaging. Most neuroradiology groups were doing spine and MPR imaging and were billing for them. Until January 1, 2006, they were getting reimbursed. Now, of course, they're not. A lot of practices took 15% hits in their revenue. It was not sensible what they were doing, but they were getting paid for 20 years doing it. Mike, what's happening at MGH?

MICHAEL E. ZALIS, MD: I want to echo something that Michael just said. My sense, after interacting with numerous third-party payers and federal payers, is that we're going to see that advance through the image processing becoming de facto, the standard package for cross-sectional imaging. I don't think that a separate charge will be possible 5 to 10 years from now. I think it is going to be rolled in as a cost-saving measure. But also practically, as more and more of our imaging studies become volume studies, it raises the question of training. We need people who are able to do the imaging that they need to do and to do it effectively.

For me, that brings up the single most important bottleneck—the software issue. There are incredibly sophisticated functions available on many of the workstations. The workflow issue really is not based on getting the patient into the room, that's a fairly fixed time. The scanner time has decreased rapidly as the technology has evolved so quickly. But often, we find the bottleneck is at the back end of the process. Since you may have 1,000 to 2,000 to 5,000 images for one examination, how does a human reader interact with that data in a time-efficient fashion to get to the clinically relevant findings as quickly and as accurately as possible?

I hope that, in the near future, there will be a real advancement in the way that human beings and imagers interact with the data. It's too clumsy on most software packages across most of the modalities. Frankly, as one example, the keyboard and mouse are sort of hold-over technology. It's not necessarily the most fluid way to interact with these large data volumes. So I would urge that there be more development on the software side to help us interact with these large data sets. Then we would need training across the board to permit that.

FISHMAN: We'll discuss training later in more detail, because that's a whole separate issue. I agree that we need to rethink the interaction with data sets. What might be the best interaction? It would be like the Nintendo Wii game system. When I was in Europe and I mentioned Wii, no one knew what it was. They thought I was speaking French!

But on the Wii, you interact with the game intuitively—you play tennis by swinging as if you were swinging a racket. Maybe we should be able to interact with the CT data set the same way. We are working on that ourselves. You could have the little clicker in your hand and just move it around in the data. I think the Wii is the second greatest invention in the history of mankind, next to the iPod.

CHARLES S. WHITE, MD: I think I would agree with everything that's been said to this point. In particular, a lot of the issue is the whole idea of getting seamless integration. We should not have to stand up, move around, move to a different workstation to get any of this work done. We have to move in the direction that the technology is—increasingly push-button types of applications with which the radiologist is the general, and everything is at his or her fingertips.

One of the other areas that I find interesting, certainly from a lung nodule perspective, is computer-aided detection (CAD). The ability to do CAD now with volumetric imaging is something we couldn't do before. Yet, one of the huge reasons it hasn't been adopted or attempted to a greater degree is that, at the moment, it is not seamlessly integrated. So I think it is absolutely crucial to move to seamless integration, which would give us the ability to do things one-touch as much as possible without moving a whole lot, since we are all very busy.

FISHMAN: We'll probably get into CAD a little bit later as well. One of the biggest changes is the workstation. Think of some of the biggest CT scanner companies in the word. Until very recently, workstations were an afterthought and were something they sold you or gave you, but they didn't put their heart into. It

wasn't something that the salesmen got commissions for, or so it seemed!

It's only at the 64-slice scanner level that they realized that you can't sell a scanner unless you have a good workstation to go with it—the scanner and workstation really are coupled. Now there are third parties who are selling workstations. Now GE and Siemens are developing workstations and building that seamless integration.

FEDERLE: I would like to touch on something Charlie mentioned. It really is important to figure out how people actually work and what they're willing to go through to make that extra step to diagnosis. If it involves leaving your workstation where you're set up to go to a different room to use a different workstation, I can tell you that most people will not do it unless they believe that it's absolutely critical to this particular case. But it won't be done routinely.

I'm involved in a publishing company for medical education and decision support, and we publish textbooks. But we also realize that, when faced with a difficult case, most people are not necessarily going to go to the department library to find help for the diagnosis. So we're trying to implement information that can be incorporated into their workstation and that can be used while they are sitting right where they are interpreting the study. We believe that will be much more effective. That reflects dealing with how people really operate in a daily setting. As long as the workstations are regarded as something exotic and something being done in specific preselected cases, it will never reach widespread application.

FISHMAN: That's a very good point. Really, this follows the client server model, which basically says that the future is not in workstations or in PACS. The future should be that you sit down in one place, and everything you could ever want is right there—including reference material, the Web, even Google Medicine.

One of the things we have all learned is that, at certain times, it's obvious that you need 3D imaging. If you want to look at renal arteries on a renal donor, it's much easier in 3D. But I would guess we have all had cases in which we didn't use 3D imaging, but we wish we had, because in retrospect, it would have made a difference in the answer. Right now, no one has the time to do all 3D imaging, or there are not enough workstations around because you can't afford them. Also, as you say, no one is going to get up and work on 2 different systems on a single case. But the question is, is this future 1 year away, or 5 years away? I think there's no doubt that the GE and Siemens models are to have a single workstation with a single workflow. I think there's no choice. Any vendor that really doesn't pursue that strategy is going to be wrong.

FEDERLE: One thing that made an immediate impact when we started using our 64-slice scanners was the ability to painlessly display simple coronal and sagittal images on every case. The technologist can preselect that as a default mode, so they don't even have to go through any extra steps. That is an immediate improvement. We happen to use GE equipment, and we have had their whole line of CT scanners over the years. Until we had 64-slice scanners, that extra step took technologists' time. Now it doesn't take any extra time.

I agree with you, even in cases in which we would not have requested the information a priori, it is not uncommon to see something in an "aha" moment, just by seeing it in a different plane. You can have a better perception of the nature of the pathology and the distribution of the pathology when you see it in a third dimension.

FISHMAN: Is your routine protocol to do that in all cases?

FEDERLE: It is, yes.

WHITE: I would like to add to something you were both talking about. At Maryland, we've moved from a model in which we did have to jump around to different machines. Now, much of what we can do is on one workstation. We can pull up the PACs and can hit a button that has been specially designed to launch a workstation tool. Now, it's a thin-client, so it doesn't have all the tools. But you can certainly do quite a bit of your work without moving. We can get into the radiology information system (RIS), and we can get into our hospital information system; so it's all right before us.

So clearly, these systems must become more sophisticated. But the days of me jumping up and down have certainly decreased somewhat. I think that's clearly part of the evolutionary process we need to continue.

FEDERLE: I cannot imagine practicing radiology anymore without being able to—at my workstation—call up the imaging as well as the hospital information system and the laboratory, pathology, and Internet-based information systems. It would just be a phenomenal step backwards if I were not able to do that. That has impacted the quality of radiology in our practice more than anything that I can imagine.

ZALIS: While it's nice to talk about solutions provided by the large vendors, like GE and Siemens, who are in a position to provide the total package, there are many smaller software vendors that work in a niche. The problem becomes how to integrate niche players who might be designing the best in their area into the larger multi-integrated, multisoftware platform. I would hope that, with industry standards to help things integrate into workflow in these very complex ways, there will be ways to have modules from different vendors interact more functionally together.

FISHMAN: I heard a good talk on that subject when someone asked the question, "What wins? Is it best of breed, or is it best integration?" That's a good question. I'm sure we all experience the curse of curses—someone coming to review a case on a disk that they brought and it's a new format. The other day I looked at 10 disks and all 10 had a different format.

ZALIS: You can't open half of them.

FISHMAN: I was able to look at 10 out of 10 that day, so we had a party. I was on that committee many years ago for the disks to develop a standard. I thought it would be a very simple committee, and we'd just pick a standard, then move on. The standard that everyone basically came to agree on was that the CD had to

be round and have a hole. Anything else you did, it didn't matter. We wanted to give people flexibility. I was off that committee after one meeting because I didn't want my name on that.

That's the fear of medical imaging; we don't want to end up with 20 disks with 20 different applications and not be able to open them. There is nothing that frustrates the referring clinicians as well as the radiologists more than the current status of how we open the CDs.

EARLS: To solve the disk problem, in part, we put an outside CD server on our network. Whenever a patient comes in with a CD, the entire contents of the CD are loaded onto the server. So, from my workstation, I just launch it from the server as opposed to from the disk drive. So, actually, I never physically see a disk anymore; but it is annotated on the records that there was an outside CD. The software is sometimes clunky, but it runs faster than trying to open the disk. Since the whole software application resides on a server, it is faster than reading back and forth from the CD drive itself. So that's sped things up.

FISHMAN: We also have a service center, but the reality is that the service center can't open half of the disks either. The fact is when the clinicians bring them to you, they are there waiting. But no one competes on the format of your disk. If you just had one format, everything would be more efficient.

ZALIS: Unfortunately, in terms of the business models of the stakeholders that drive these particular facilities and software innovations, they see it as an advertisement of their own particular kind of software. Often, when we put an outside disk in the machine, we get a big splash screen of a particular imaging center or a particular device maker. They have their 5 seconds of your attention, and they lock you in so that you have to use their software. I think it's a marketing tool.

WHITE: You shouldn't be surprised. Look how long it took DICOM to become even minimally standardized.

ZALIS: Well said. The quote from hackers who actually get into software programming for DICOM is "if you've seen one DICOM, you've seen one DICOM!" Unfortunately, it's not actually that standard a standard.

HAAS: But DICOM is still a challenge, because when you look at these new applications, all vendors are doing their DICOMs differently. Until they become standardized, when we talk about workstations, you can't load one vendor's images onto another workstation. So that's a challenge we have to work on as an industry.

FISHMAN: But I think the good news, from what I understand, is that on the iPhone, we'll be able to read any disk, any bit of information in any format. But Steve Jobs has not yet announced that, so I don't want to pre-empt it.

Current status of CT technology

While 16-slice CT scanners remain workhorses for general applications, 64-slice scanners set the standard for cardiac imaging. At all levels, the future lies in streamlining through automation.

DeAnn Haas

Ms. Haas is the Global Cardiovascular CT Marketing Manager for GE Healthcare, Waukesha, WI.

Computed tomography (CT) has changed rapidly in a short time. This article reviews the predominant CT technology in use today: 16-, 32-, and 64-slice scanners as well as new dual-source scanners. Increasingly popular CT applications will also be discussed, including CT colonography, lung CT, cardiac CT, and vascular CT.

Technology

Years ago, CT was defined by axial imaging, as patients moved through the scanner image-by-image, as each scan was acquired. Today, with the exception of certain forms of brain imaging, virtually all CT scanning involves the use of multidetector helical CT technology. The scan table moves through the scanner without interruption as the detector continuously rotates around the patient.

All major CT vendors, and a growing number of smaller ones, offer 16-slice CT scanners. With 16-slice scanners, the middle of the detector is composed of 16 slices, each 0.5, 0.625, or 0.75 mm in width, depending on the vendor. Coverage for thin-slice acquisitions is 10 to 12 mm per rotation. In addition, thicker cells make up the outer regions of the detector. When neighboring cells from the middle of the detector are combined together and used with the surrounding thicker cells, images can be acquired at 1, 1.25, or 1.5 mm, and coverage expands to 20 to 24 mm. Sixteen-slice scanners are useful for all general applications.

Similarly, 32- and 40-slice scanners are composed of a middle region with detector channels ranging in width from 0.5 mm to 0.75 mm and offering coverage of 16 to 20 mm. Flanking the middle are paired regions of 1.25-mm-thick detector cells. When images are acquired using thicker slices, the total coverage expands to 32 to 40 mm.

Realistically, 32- and 40-channel scanners today represent baseline technology for performing cardiac CT studies. Although 16-slice scanners are still used for this purpose with good results, cardiac studies are more consistently successful with 32-slice, 40-slice or, more commonly, 64-slice scanners.

With 64-slice scanners, there is more variation from one vendor to another in slice thickness and coverage (Figure 1). On the LightSpeed VCT (GE Healthcare, Waukesha, WI) and the Brilliance CT 64-channel scanner (Philips Medical Systems, Bothell, WA), the detector is composed of 64 cells, each 0.625-mm thick throughout the entire 40-mm coverage area. Using these scanners, a cardiac CT scan can be completed in approximately 5 to 8 seconds. The Aquilion 64 (Toshiba America Medical Systems, Inc., Tustin, CA) also has a 64-channel detector, but the cells are thinner (0.5 mm). As a result, the coverage is 32 mm, and a cardiac CT scan takes a little longer to complete — approximately 7 to 9 seconds. With all 3 of these scanners, it is possible to scan with thicker slices through the use of software that combines detector cells.

The SOMATOM Sensation 64-slice scanner (Siemens Medical Solutions, Malvern, PA) acquires 0.6-mm slices over a coverage of 19 mm from 32 channels in the middle of the detector. The acquisition of 64 slices per rotation is accomplished through double z-sampling, which involves the use of 2 detectors, alternating focal points, and overlapping 0.6-mm samples. In this case, coverage remains 19 mm. There are also 1.2-mm cells on the outer regions of the detector, expanding the coverage during thick-slice acquisitions to 29 mm. On this scanner, a cardiac CT scan takes 10 to 12 seconds to complete.

Dual-source CT (currently available on the Siemens SOMATOM Definition) is a recent addition to the CT market. As its name implies, dual-source CT consists of 2 X-ray tubes and 2 detectors that rotate around the patient from 2 different angles (Figure 2). Each detector is composed of a middle region with 32 cells, each 0.6-mm wide, providing a coverage of 19 mm. Detector A performs a full scan with a 50-cm field of view (FOV), whereas Detector B performs a restricted scan with a 26-cm FOV. One of the key benefits of dual-source CT is an improvement in temporal resolution to 83 msec, expanding the range of heart rates acceptable for cardiac imaging.[1] On a dual-source CT scanner, a cardiac CT scan takes 8 to 10 seconds to complete.

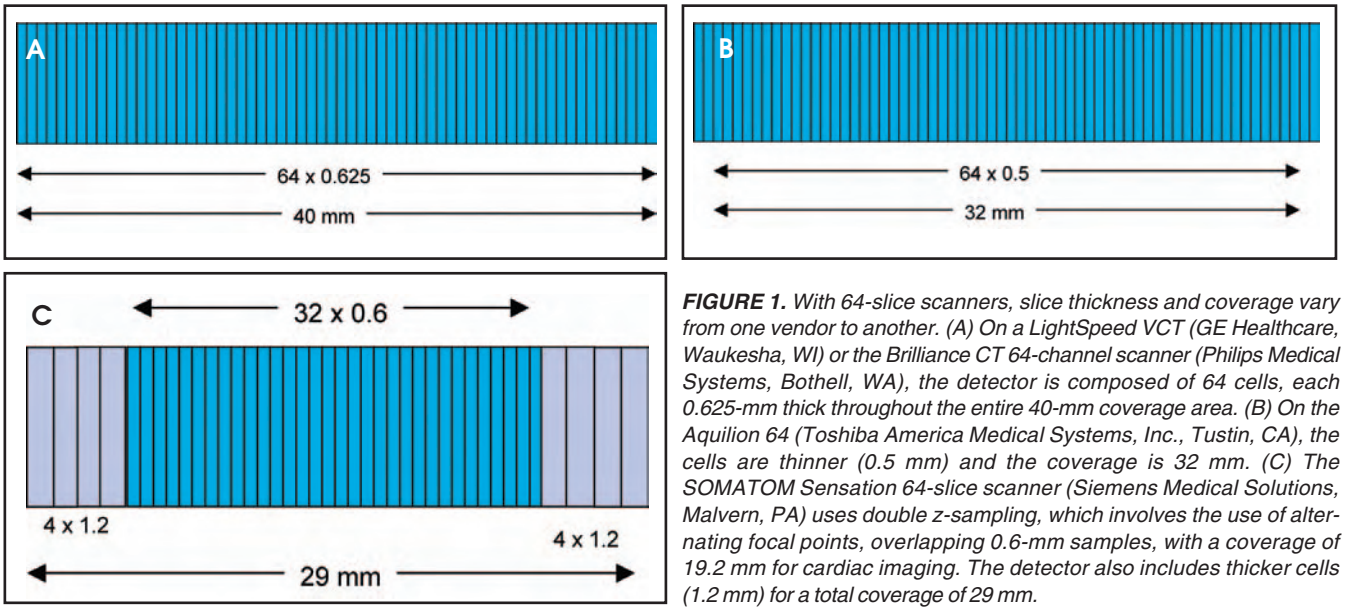

FIGURE 1. *With 64-slice scanners, slice thickness and coverage vary from one vendor to another. (A) On a LightSpeed VCT (GE Healthcare, Waukesha, WI) or the Brilliance CT 64-channel scanner (Philips Medical Systems, Bothell, WA), the detector is composed of 64 cells, each 0.625-mm thick throughout the entire 40-mm coverage area. (B) On the Aquilion 64 (Toshiba America Medical Systems, Inc., Tustin, CA), the cells are thinner (0.5 mm) and the coverage is 32 mm. (C) The SOMATOM Sensation 64-slice scanner (Siemens Medical Solutions, Malvern, PA) uses double z-sampling, which involves the use of alternating focal points, overlapping 0.6-mm samples, with a coverage of 19.2 mm for cardiac imaging. The detector also includes thicker cells (1.2 mm) for a total coverage of 29 mm.*

CT colonography

Colon cancer is the second most common cause of cancer-related death in America.[2] It is highly treatable, however. When colorectal cancer is detected at an early stage, the 5-year survival rate is 90%. Unfortunately, only 39% of colorectal cancers are diagnosed at this stage. It is essential, therefore, that we consider new ways to encourage patients to undergo screening for colon cancer.

One of the most promising new diagnostic options is CT colonography. This technique has several key advantages over conventional colonoscopy; among them, it is more comfortable, it takes significantly less time to perform, and it does not require sedation.

As with any new application, CT colonography must overcome certain challenges and criticisms. One criticism is the failure to achieve consistently high sensitivity for the detection of polyps; however, several studies have reported sensitivities >90%.[3-5] Study interpretation is difficult and fatiguing and is associated with a steep learning curve. In addition, there is high inter-reader variability in the detection of polyps, and the detection of flat adenomas is challenging. Moreover, patients must still complete unpleasant colon preparation prior to the study, insufflation is uncomfortable, and additional conventional colonoscopy is required if polyps must be resected.

As vendors, we are working with our physician partners to explore various ways of addressing these criticisms and improving clinical acceptance. Beyond our own internal studies, the American College of Radiology Imaging Network (ACRIN) is conducting a multicenter clinical trial to explore the sensitivity and clinical effectiveness of virtual colonoscopy. Data from this trial might also aid in another important initiative: Achieving reimbursement from health insurers. Today 47 states offer some sort of reimbursement for CT colonography after failed or contraindicated optical colonoscopy.

Work is also under way to improve the patient experience, for example, by finding ways to eliminate the need for colon preparation before CT colonography. In addition, all vendors are working to improve reading techniques. Computer-aided detection (CAD) and computer-aided reading (CAR) can automatically identify polyps for the physician, who then reviews the data set to accept or reject the software findings. Newer scanners can acquire data in very thin slices, enabling the creation of high-resolution 3-dimensional (3D) "fly-through" images. The synchronization of prone and supine views in the creation of fly-through images enables the evaluation of all polyps in a simultaneous prone and supine comparison reading. The colon can be presented in a "filleted view," for improved polyp detection.

Lung CT

Lung cancer is the leading cause of cancer-related death. Last year, an estimated 174,000 new cases of lung cancer were diagnosed, and an estimated 162,000 Americans died of this disease, representing 29% of all the cancer deaths. Since 1987, more women have died each year from lung cancer than from breast cancer.[2]

There is a compelling need to improve the early detection of lung nodules so that treatment of lung cancer can be initiated before the disease progresses to an advanced stage. CT is a high-resolution imaging modality that can enable the visualization of nodules at a very early time point.

It is, however, important to explore the relative costs and benefits associated with CT lung nodule imaging. A common concern is whether early detection will actually result in earlier and more successful treatment of patients, or if it will become an economic burden on the healthcare system. In addition, the discovery of anomalies, clinically relevant

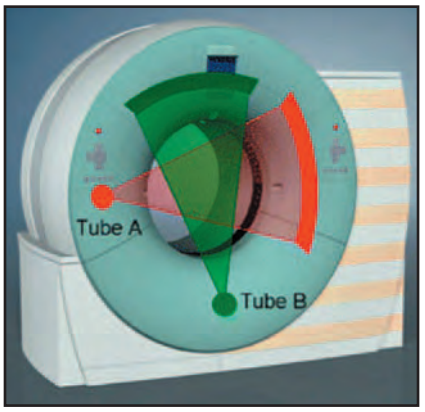

FIGURE 2. *Dual-source CT consists of 2 X-ray tubes and 2 detectors that rotate around the patient from 2 different angles. Each detector is composed of a middle region with 32 cells, each 0.6-mm wide, providing a coverage of 19 mm. Detector A uses a full-scan field of view (50 cm), whereas detector B uses a restricted scan field of view (26 cm). (Figure reprinted with kind permission from Springer Science and Business Media from Flohr TG, McCollough CH, Bruder H, et al. First performance evaluation of a dual-source CT [DSCT] system.* Eur Radiol. *2006;16:256-268,*[1] *Figure 1. Copyright 2006, Springer Science and Business Media.)*

or not, may cause patients to become anxious and fearful.

As vendors, we are taking a multipronged approach to improving clinical acceptance. Early detection of disease is an important goal. Several ongoing trials are evaluating clinical effectiveness, including the International Early Lung Cancer Action Program, developed by physicians at Weill Medical College of Cornell University (New York, NY).[6,7] We are also looking at ways to increase sensitivity and reduce the rate of false-positive findings.

All vendors are focusing on ways to improve reading efficiency through CAD and CAR algorithms and other strategies. Typically, physicians first review the data set for lung nodules and then use CAD to ensure that no abnormalities were missed. New technology is also able to facilitate diagnosis by not just detecting lung nodules but also by defining them as solid, partially solid, or nonsolid. It may also be useful for differentiating benign from malignant lesions.

Figure 3 shows a 65-year-old smoker with a lung nodule discovered on a chest

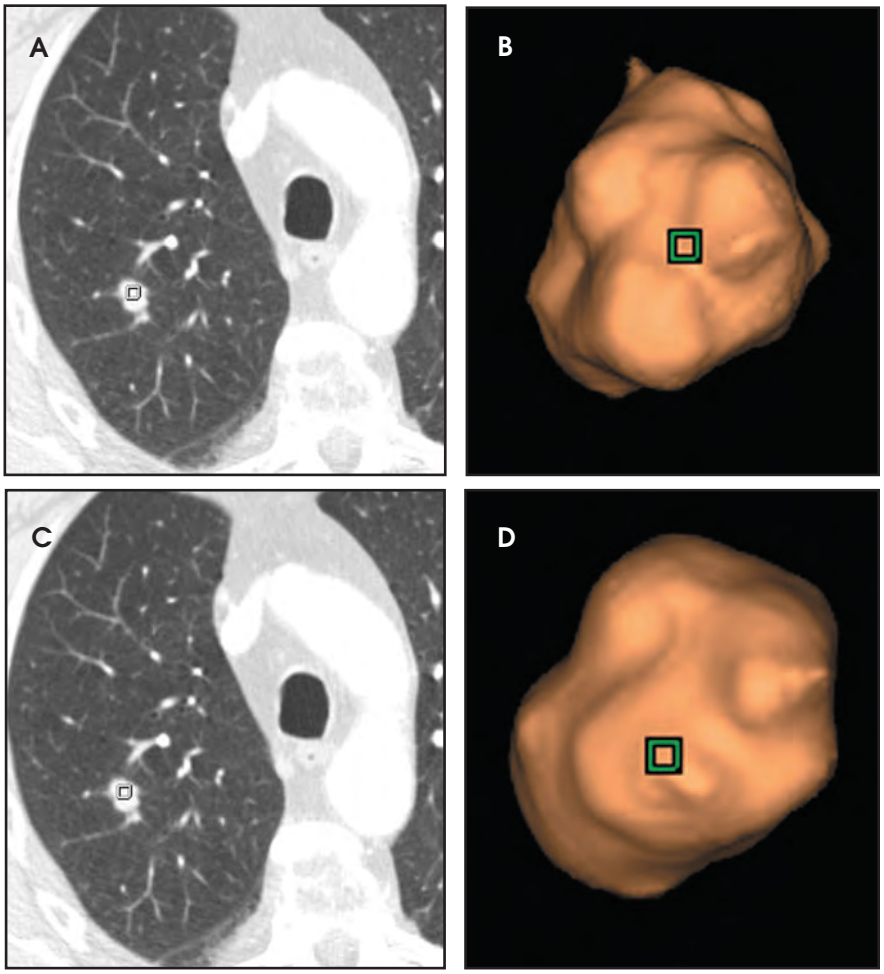

FIGURE 3. *A 65-year-old smoker with a lung nodule that was discovered on chest X-ray. (A) CT confirmed the presence of the nodule. (B) Computer-aided read (CAR) software documented a volume of 769 mm^3, which was confirmed by the physician. (C) A second CT scan was performed a few months later. (D) At that time, CAR software measured a 35% increase in the volume of the nodule, to 1038 mm^3, and calculated a doubling time of 255 days, which was suggestive of malignancy. The patient underwent surgical resection. The pathologic examination showed a stage I adenocarcinoma. (Images courtesy of M.P. Revel, A. Bissery, M. Bienvenu, L. Aycard, C. Lefort, and G. Frij, Assistance Publique–Hôpitaux de Paris, Paris, France.)*

X-ray. CT confirmed the presence of the nodule, documenting a volume of 769 mm^3. On a second scan a few months later, CAR software measured a 35% increase in the volume of the nodule, to 1038 mm^3, and calculated a doubling time of 255 days, which was suggestive of malignancy. This finding was confirmed by the physician. The patient underwent surgical resection. The pathologic examination revealed a stage I adenocarcinoma.

Cardiac CT

Heart disease is the number-one killer in the United States. More than 79 million Americans have some form of cardiovascular disease, and one American dies of cardiovascular disease every 36 seconds. In fact, cardiovascular disease claims more lives each year than the next 4 leading causes of death combined. Moreover, it is not just a disease of men; rather, beginning at age 75, the prevalence of cardiovascular disease is higher in women than in men.[8]

Cardiac CT is among the most exciting developments in CT today. Nonetheless, like CT colonography and CT lung studies, cardiac CT faces both challenges and criticisms. One of the most commonly cited concerns is radiation

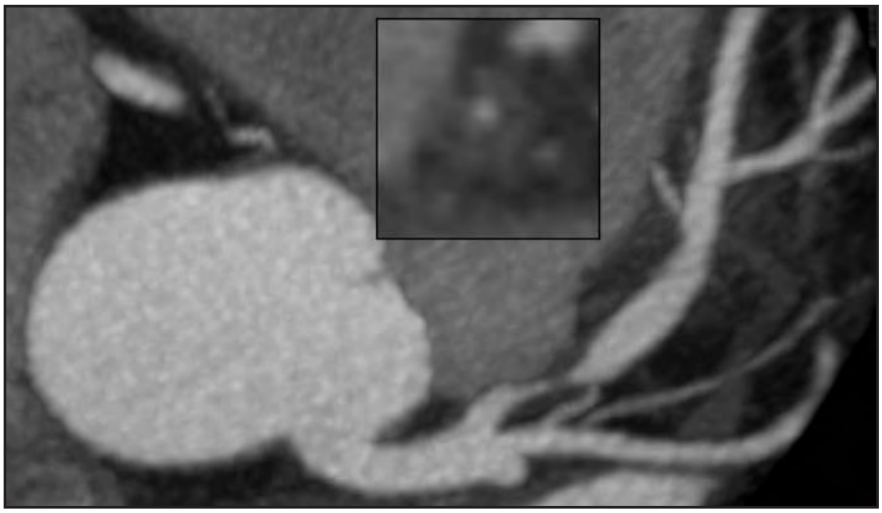

FIGURE 4. *Coronary CT angiography displays a noncalcified plaque that is causing a proximal stenosis of the left anterior descending coronary artery.*

dose, which has been reported to be in the range of 8 to 20 mSv per study.[9-12] To address this concern, several vendors have introduced new techniques for dose reduction, which will be discussed later.

There is also a need for clinical validation of cardiac CT. Its high negative predictive value is well established; indeed, it was reported to be 93% to 99% even in early studies.[13-18] The question is, does detection of heart disease with CT improve patient outcomes? Several studies and registries are under way to determine outcomes, the cost-effectiveness of CT, and the appropriateness of CT.

Vendors are also working to reduce the time it takes to read a study, which for coronary CT angiography (CTA) has

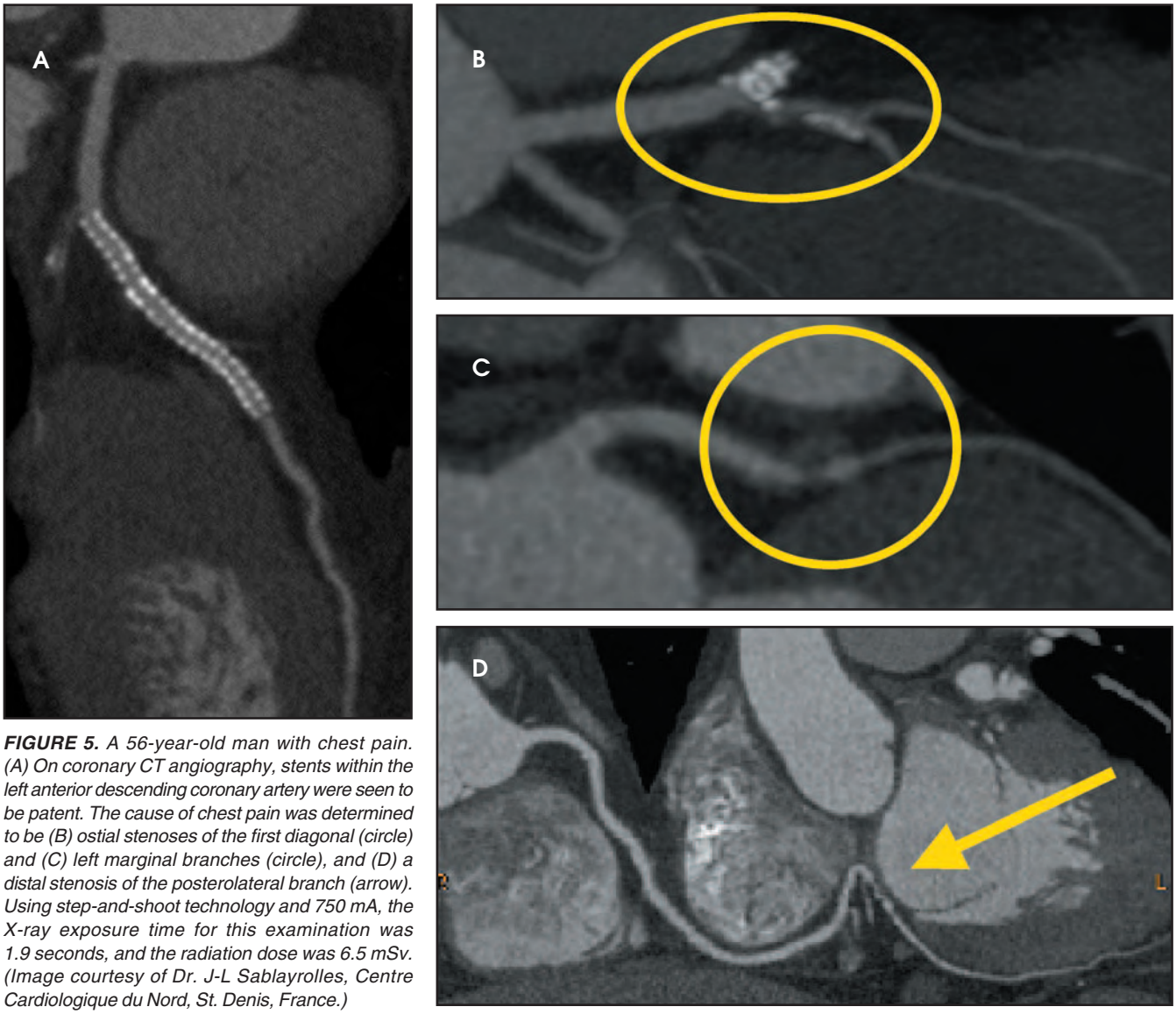

FIGURE 5. *A 56-year-old man with chest pain. (A) On coronary CT angiography, stents within the left anterior descending coronary artery were seen to be patent. The cause of chest pain was determined to be (B) ostial stenoses of the first diagonal (circle) and (C) left marginal branches (circle), and (D) a distal stenosis of the posterolateral branch (arrow). Using step-and-shoot technology and 750 mA, the X-ray exposure time for this examination was 1.9 seconds, and the radiation dose was 6.5 mSv. (Image courtesy of Dr. J-L Sablayrolles, Centre Cardiologique du Nord, St. Denis, France.)*

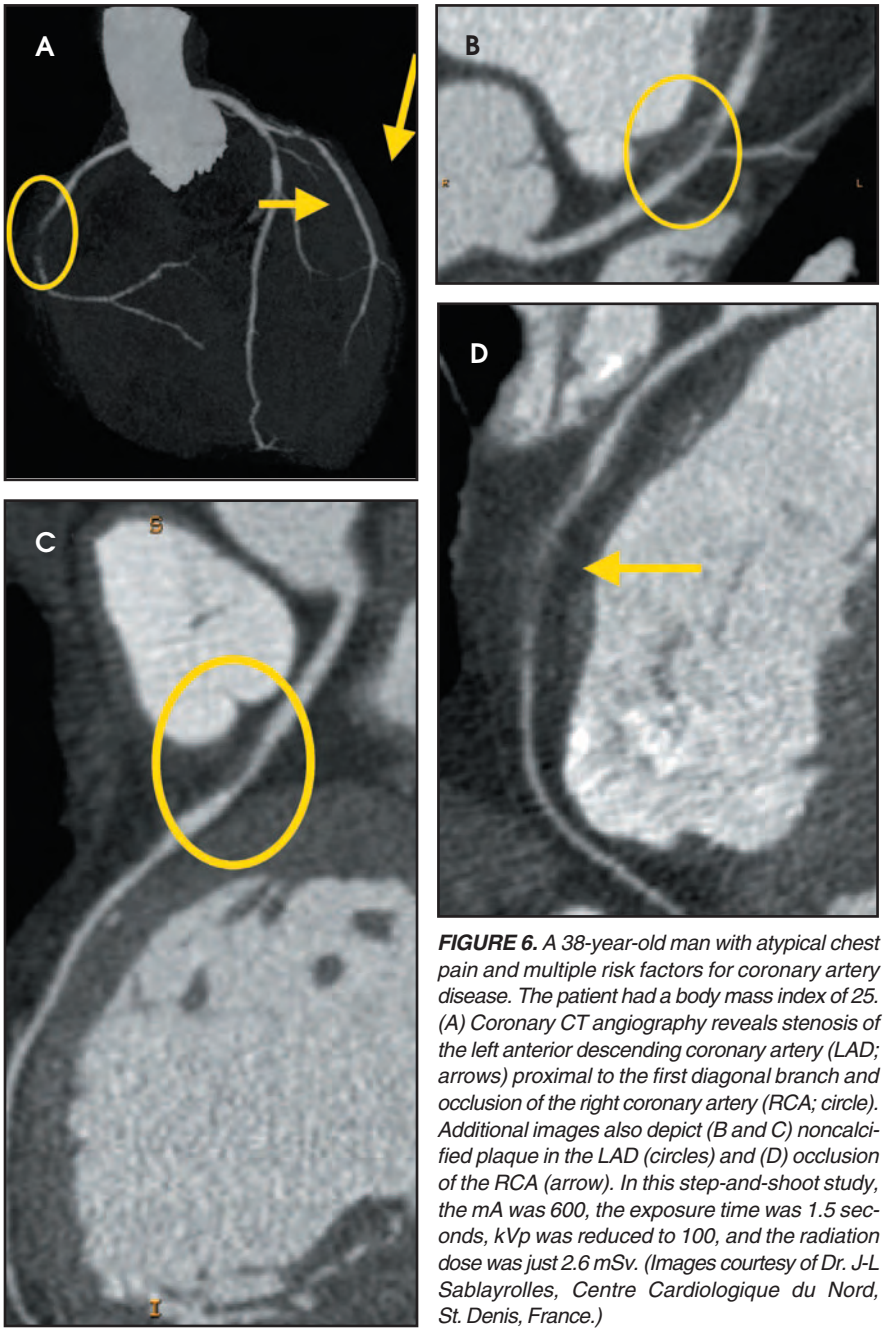

FIGURE 6. *A 38-year-old man with atypical chest pain and multiple risk factors for coronary artery disease. The patient had a body mass index of 25. (A) Coronary CT angiography reveals stenosis of the left anterior descending coronary artery (LAD; arrows) proximal to the first diagonal branch and occlusion of the right coronary artery (RCA; circle). Additional images also depict (B and C) noncalcified plaque in the LAD (circles) and (D) occlusion of the RCA (arrow). In this step-and-shoot study, the mA was 600, the exposure time was 1.5 seconds, kVp was reduced to 100, and the radiation dose was just 2.6 mSv. (Images courtesy of Dr. J-L Sablayrolles, Centre Cardiologique du Nord, St. Denis, France.)*

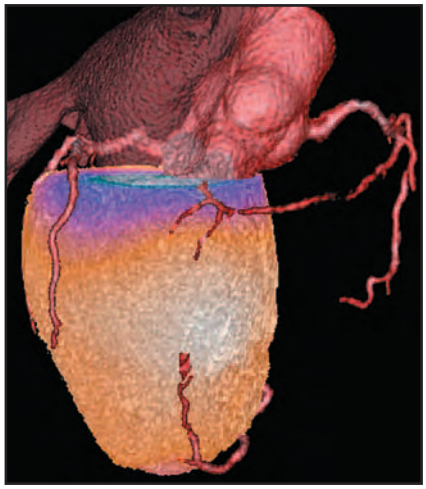

FIGURE 7. *This is a positron emission tomography (PET)/CT image in a 43-year-old woman with coronary artery disease risk factors who had typical stable angina, cardiac enzymes, and negative electrocardiographic results. Coronary CT angiography indicated mixed plaque in the left anterior descending artery; the results were questionable in the right coronary artery (RCA) due to suboptimal visualization but suggested significant luminal narrowing. A rest/dipyridamole rubidium-82 PET scan revealed a moderate reversible perfusion defect in the inferior wall, which suggested ischemia in the RCA territory. The PET scan indicated that there was no infarct and determined a left ventricular ejection fraction of 40%. (Image courtesy of Frank M. Bengel, MD, Director of Cardiovascular Nuclear Medicine, Johns Hopkins Medical Institutions, Baltimore, MD.)*

typically been longer than for other CT studies. Reading time improves with experience, but vendors have also addressed this concern by developing postprocessing software that automatically creates reconstructions of the heart and coronary arteries and provides information on cardiac function. This ability to automate processing will improve overall reading time and will be especially useful in the emergency room setting.

Key requirements for cardiovascular imaging include excellent spatial resolution, excellent temporal resolution, consistent examination reliability, and a reasonable radiation dose. Today, spatial resolution may be as low as 0.35 mm but ranges between 0.7 and 1.0 mm, which enables the visualization of vessels <1 mm in diameter and the detection of stenoses of >50% (Figure 4). Coronary CTA also has the potential to detect in-stent restenosis in the proximal and mid coronary arteries. As impressive as such achievements are, it is important to keep in mind that conventional angiography has a spatial resolution of 0.2 mm. Therefore, there is still a need for improvements in spatial resolution to enable more precise quantitative evaluation of vessels.

An important goal in cardiac CT is "freezing" the motion of the heart. All scanners on the market today have a temporal resolution ranging from 165 to 210 msec. Still, in many patients, the use of beta blockers may be necessary in order to reduce the heart rate to an acceptable level (<70 bpm) and eliminate motion artifact. It is possible to image patients with high heart rates using 64-slice CT and multisector imaging. As mentioned earlier, one of the benefits of dual-source CT is its ability

to lower temporal resolution to 83 msec, thereby expanding the range of heart rates that are appropriate for cardiac CT.

As important as improvements in spatial and temporal resolution are, the increased coverage area introduced with 64-channel detectors is responsible for making cardiac CT a reliable examination. As compared with a 16-slice scanner, which takes approximately 25 seconds to image the heart, a 64-slice scanner with a 40-mm detector can image a 12.5-cm heart in just 5 seconds.

Electrocardiographic (ECG) dose modulation is a critical feature in any scanner on the market today. Depending on the version of scanner, it is possible to use ECG dose modulation either with heart rates <65 bpm, or with any heart rate. On all scanners, when the heart rate is ≤65 bpm, it is recommended that peak mA be used during diastole (70% to 80% of the R-R interval) and that the mA be dropped during systole. If the scanner is capable of allowing modulation from end-systole to end-diastole (40% to 80% of the R-R interval), it is recommended that this mode be used for patients with heart rates >65 bpm, as it offers the potential to review the coronary arteries in both the diastolic and systolic phases.

Electrocardiographic dose modulation can reduce radiation dose by roughly 20% to 50%, as compared with a typical coronary CTA. In addition, image quality filters enable a reduction in the dose by reducing image noise.

Some vendors have recently introduced step-and-shoot technology to cardiac imaging. This is a form of prospective ECG gating, in which axial data are acquired during the diastolic phase of the heart cycle. This step-and-shoot approach reduces radiation dose up to 70% while slightly improving image quality. One of the limitations of this technology is the inability to acquire data for functional imaging. While functional imaging is an important diagnostic test, some patients may already have had a functional examination by ultrasound, magnetic resonance, or nuclear medicine. The physician has a choice, depending on the clinical need, to do a step-and-shoot CT examination, which reduces the radiation dose to the patient, or a helical examination, which includes information on cardiac function.

Figure 5 shows an example of step-and-shoot technology. The patient was a 56-year-old man with chest pain. Coronary CTA showed an absence of restenosis within 2 stents implanted in the left anterior descending (LAD) coronary artery. However, it also showed ostial stenosis in the first diagonal and left marginal branches, and a distal stenosis of the posterolateral branch. Note that through the use of step-and-shoot technology, the X-ray exposure time for this examination was limited to 1.9 seconds, and the radiation dose to 6.5 mSv.

In smaller patients, another way to reduce radiation dose is to combine step-and-shoot technology with a reduction in kVp to 100. (This technique can also be used to the reduce radiation dose with helical imaging.) Figure 6 displays a 38-year-old man with a body mass index (BMI) of 25, atypical chest pain, and multiple risk factors for coronary artery disease. Coronary CTA revealed a stenosis in the LAD proximal to the first diagonal branch and an occlusion of the right coronary artery. In this study, the exposure time was 1.5 seconds and the radiation dose just 2.6 mSv. In patients with a BMI <30, it is possible to reduce the kVp to 100 and achieve a radiation dose <1.0 mSv.

Cardiac fusion is another exciting application. In this technique, data from coronary CTA is fused with perfusion data from positron emission tomography (PET) or single-photon emission computed tomography (SPECT). Such studies can be performed using separate CT and PET or SPECT scanners, or the new combined PET/CT scanners. This combination of data enables evaluation of both anatomic and physiologic evidence of stenosis (Figure 7).

Vascular imaging

Approximately 8 to 12 million people in the United States have peripheral arterial disease. By 2050, that number is projected to increase to 19 million. Approximately 30% of patients will ultimately require open surgical or percutaneous revascularization.[19,20]

CT is already an excellent option for vascular imaging. The emphasis today is on improving vascular imaging software so that 3D reconstructions can be performed routinely. New software exists for vascular imaging of the head and neck, for example. The software automatically segments and removes bone, making it easy to visualize and evaluate the carotid arteries and the circle of Willis. New software will also enable automatic detection and analysis of the aorta with a single click, including detection and measurement of thrombus.

In the future, the vascular data will be automatically transferred to the workstation for processing, so that images will be available for interpretation as soon as the user is ready. In addition, new software is becoming available to help in planning for thoracic and carotid stenting.

Conclusion

CT technology has been rapidly changing over the past few years, and this has returned CT to the spotlight. It has been amazing to see how newer applications, such as cardiac CT and CT colonography, have become mainstream procedures in many practices today. As new CT scanners are introduced, even more advanced applications could be developed that may have the potential to improve patient care.

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Discussion

ELLIOT K. FISHMAN, MD: Knowing what you know, what would make the biggest difference in CT technology? Forget for the moment that you work for GE.

DEANN HAAS: It's hard to say one thing is going to make a difference. But I think one of the biggest things that we've really started to talk about is automation. It's clear that all of the vendors are going to go to automation. To actually bring 3D into routine clinical practice, we need to automate processing. As you said at the University of Pittsburgh, the automatic coronals have no reconstructions. If we can automate coronary imaging for you, so all your curved reformats, your lumen views, your cross-section, and your 3D images are there for you and done, we're automating the applications of the thoracic aorta and the abdominal aorta, we can actually improve your reading times.

CT is growing and we're seeing procedure rates grow. We're starting to do a lot of new procedures. So we really need to automate these procedures, so your read times stay consistent with what they are today.

FISHMAN: It's interesting; it goes back to when we talk about technology as a scanner, the hardware, and then the workstations, which I would consider software. So now there is a blurring between the two.

HAAS: But what's happening now is that the applications are selling the scanners. Would there really have been a need for 64-channel detectors if cardiac CT didn't come to fruition? We can do a lot of the procedures today on the 16-channel system. So you need the CT for the 64 channels? When you look at the new detectors and the 256-channel, what is that going to bring us? That's a potential for a four organ in a rotation. Could perfusion now become a very good tool with CT? There are a lot of different technologies to think about.

What's interesting is that you will see all the vendors go in a different direction now. One will go with temporal resolution, another with coverage, and another with spatial resolution. Right now, we're going to be in a unique time during which the physicians can actually choose what is going to be beneficial to them in their practice, based on which disease states they are looking at.

FISHMAN: Charlie, what would be your favorite thing?

CHARLES WHITE, MD: I would more or less agree with DeAnn. Basically, to try to streamline things, we need to get the fastest software and now we require a 3D tech, there's no question. Certainly, we can do it and we train our fellows to do it. But the bottom line is that it takes extra time and we do a fair amount of cardiac CT right now.

If you look at it as a financial model, it doesn't really make sense to do cardiac CT because it takes so long. The payback for the amount of time that you take just isn't there. So clearly, I think the best thing would be if we could get it to be 1) integrated; and 2), one-touch. Those would be the two things I would wish for.

MICHAEL E. ZALIS, MD: I'm touching on the points differently than my two colleagues here. It's useful to look at what has not changed in imaging with the advent of all these new technologies. The radiologist doesn't have any more time to spend per case and probably has less, given the reimbursement rates. It takes about the same amount of time as it used to to bring a patient on and off the scanner, and roughly the same amount of time scanning, even if we're getting the special artery images. While we used to print things and look at them on film, now we have very fast processing, really real-time images, and we can get our images on the PACS and get them routed through the Ethernet to whatever station we're working on. So the transmission time from scanner to a form that our reader can read hasn't changed terribly much.

That all creates a set of constraints that the human has to interact with. What has changed, as we've talked about, is the fact that we now have huge volumes of information that we expect people to try to integrate and diagnose based upon. It then basically comes down to software as a solution that will allow us to take this enormous volume of data and boil it down to a form that a human can effectively interpret in a short period of time.

FISHMAN: Mike, in your practice, what is the biggest challenge for you at work day-to-day?

MICHAEL P. FEDERLE, MD: I think with the sheer volume of studies to be done, the challenge is in the fatigue factor of having to analyze so many images per patient. A routine study includes hundreds of images. It is not uncommon to be doing 30 to 50 CT interpretations a day of that image volume. One of the biggest issues is in dealing with the clinical and the radiologic information, to synthesize it all and get a meaningful report out quickly.

FISHMAN: Elliot Siegel was doing something last year in which he figured that when you are looking at thin slices in a typical busy practice, you are looking at 80,000 slices or more per day. I haven't been doing CT as long as you have, Mike, but I come close. I think that, many days, the number of slices I look at in a single patient totals more than the number of slices I looked at in an entire day roughly 10 years ago. This would be about 3,000 slices. If we were doing doing 100 slices a patient at that time, with 30 patients a day, that was 3,000 slides. Now you finish that many slices by 7:36 in the morning! It is a challenge.

JAMES P. EARLS, MD: We are getting pressure from all sides. The payers are paying us less money, so we have to do more studies to make up for that. But the technology is also pushing us with the ability to do all of these additional slices. I think it would help to have some cohesion of all the tools that we have, so that I'm assured that I'm not missing things clinically. Back in the days when I started out, a CT scan was 3 or 4 sheets of film—now that's the scout piece. Not that I read sheets of film anymore. But there are so many images that it is difficult to not miss things. So I would want tools to help me, whether it be CAD, or CAR, or whatever those tools are, that bubble up and really become something that I could use clinically, and not just see at conferences.

FISHMAN: It's a good point. We've been doing 3D imaging for many years, really from the beginning. Now it's come to fruition that 3D is actually something that you're supposed to do. I agree that the biggest challenge we have at Hopkins is just the sheer volume of material. We used to think in radiology that whatever you read, you had 30% or 50% capacity to read more. Then the PACS made it more efficient, and RVUs per full-time equivalent grew even more.

I think right now—and I've told our chairman this—that I would say people are maxed out. I don't think you have 10% fat in the system for reading. People are reading to their capacity. They're not going to read anymore, they don't want to read any more studies, and maybe they just can't read anymore. So I just wonder if we need to really rethink the process. The way we read now is that we're making things as efficient as we can, with the way we did things for 30 years. We've kind of optimized that process.

Maybe we need to start again on how we approach this. The question is, if you just looked at coronals, you would look at one tenth of the number of slices compared with the axials. So, do you really need to look at the axial images? It's kind of the reverse way around. If you started from the beginning and said, all we have are coronals for routine CT, and you want to go back and get a few axials, would that work?

A couple of articles have shown it's pretty close. That would be a whole different way of doing things, and you would decrease the number of slices you have to look at by 90%. Is that doable? I don't know, in reality. It's doable physically, but is it doable from an accuracy perspective?

FEDERLE: Let me throw out a completely different type of challenge, something we haven't touched on at all. I spend a lot of time at my hospital on this and in interdepartmental meetings. We all agree that we can design protocols that are the optimal way to evaluate chest pain, or suspected colonic polyp, or certain small bowel diseases. If the referring clinician has not identified what it is they are most concerned for us to look for, we really have trouble designing the optimal protocol.

In our hospital, the administration spends a lot of time trying to simplify the ordering process. They want to make it a one-click process. So, paradoxically, we may get even less information from the referring clinicians as to what information they want from the CT scan. So that is a real challenge for us. We know that with certain referring doctors, almost every patient they send us is sent for abdominal pain, regardless of what he is really thinking in his mind. Some of the vascular surgeons' secretaries click "rule-out aortic aneurysm" even if that has nothing to do with what the patient is being sent for.

If we don't have access—right at the workstation—to the patient's medical record and other information, we cannot do a decent job of practicing radiology. We wind up having to elicit for ourselves what's going on with the patient so we can design the proper protocol. This is something we really face.

We want automated, easy systems. More and more, we're trying to move work away from the physician to less expensive staff. But, in the process, we're really missing out on some of that face-to-face communication with the referring physicians that sometimes allowed us to make a more intelligent interpretation. So those are some of the challenges we face, and they don't necessarily have to do with CT technology or contrast agents. But it is a significant factor.

EARLS: That's an interesting observation, the orders of magnitude of additional data in every field except for the clinical question. We are still back to "rule out" things. I wind up using the HIS and RIS to find out what the patient's other studies found, so I can figure out what I think the clinical question might be, rather than just getting it from the horse's mouth.

WHITE: Ironically, that integration of all the technology, including the CT technology and the HIS, allows you to get around some of the limitations of the system. Before, all we heard was "rule-out atelectasis," and I still see that all the time. We're talking about chest X-rays here! But now, we can get around it. So,

in a sense, not only does CT technology provide us with some of the answers, but general information technology has allowed me find some answers. That has to be part of the whole picture.

FISHMAN: We have implemented electronic patient ordering, also, which is conceptually the greatest thing in the world because you should have all the information. But, in reality, you have less information than ever. They know the minimum you have to press to get to the next screen, and they press that minimum bit of information. You're right, it's worse than ever. It is the "rule-out thorax disease." But we have access to incredible amounts of information.

It used to be so hard in the old days to get follow-up for cases, and now you get the pathology reports online. In saying that, there comes a time when you spend more time chasing the information than in reading the scans. So there has to be some way to streamline that process too. There's no doubt that PACS created an issue; since other people can see films, they don't need to come to you, and you lose the face-to-face time. In our training and faculty positions, we've all spent hours and hours each day with people coming through—group after group—looking at images.

Now, I still do that because we read at the scanner. But I only speak to professors because the residents (who are on 80-hour work weeks) are not allowed to leave the floor. I'm sure all institutions are the same because they need the residents to be working. The full-time staff is not on the clock, so they are the ones coming down to see you. So I have a parade of professors, but I haven't seen an intern in 3 years or so—maybe just on the weekends or something.

But there has to be some way with the information systems to address this. Years ago, we had to keep searching, but now in 5 minutes you will find the answer. But that's an incredible waste of time when you are looking at 50 cases. I'm spending 3 hours a day chasing patient histories. There has to be another way.

Compared with other fields, one solution radiology and imaging have not used is physician assistants (PAs). I don't think Hopkins, or probably most institutions, would exist without PAs. Surely, oncology would not exist without them. Who is bugging you to get tumor volumes? It's not the oncologist, it's their PA. That's their life's goal, to get someone to fill out the forms for that trial. There must be some way in which you have an intermediary person who could say, "Here's the reason this study was done." For the most part, a PA can figure it out. I need the information, but it's a waste of time for me to spend 5 minutes a case looking for that.

FEDERLE: Let me tell you something I think can be done with intelligent use of information technology. I spend a lot of time at the hospital running a task force on contrast-induced nephropathy (CIN) and how to decrease the incidence and so forth. We know a lot about CIN and how to prevent it. But the most important thing is to know who is the at-risk patient that you are going to be scanning. It's hard enough getting a proper history of why you are doing the CT scan. It's another thing to ask the referring clinician, "Tell me your patient's weight, gender, race, etc."—yet these factors are all important in figuring out glomerular filtration rate, for instance, or whether the patient is diabetic. We're trying to develop a system so that if the answers to certain questions are negative, the patients are low-risk patients and they don't need to go through anything more.

But if a patient has positive answers to a couple of quick questions (such as does your patient have diabetes or is there any history of renal insufficiency), a physician or PA will have to take an extra couple of seconds to let us know that. That way, we can prospectively identify patients at risk for CIN, so we can take the proper steps, which might be administrating an isosmolar contrast agent or increasing hydration.

We're all faced with the situation. If you have a patient on your table, and the tech tells you, "I just found out that the patient's diabetic and he has only 1 kidney," you have very few options as to what to do at that point. You can either not give contrast at all, or incur the risk of CIN.

I think there needs to be a lot of additional work, with technology and with staff, in trying to identify an orderly process that would help provide us with the information we need to properly design protocols.

FISHMAN: Do you require serum creatinine levels for your patients who come in for CT?

FEDERLE: We do not routinely require it.

FISHMAN: Jay, do you require it in all patients regardless?

EARLS: We do. In our outpatient practice, every patient gets a creatinine at the time of the IV draw, since we have small point-of-service creatinine machines. So when we put the angiocatheter in, we take a couple ccs of blood out and run a creatinine level right then. In the past, I had required outside creatinines. But 10% of patients show up without them, so 10% of studies were cancelled. This way, no study is ever cancelled for lack of a creatinine level.

FEDERLE: We are probably going to do it the same way, now that apparently the instant creatinine test is sufficiently accurate to rely upon.

ZALIS: Aside from the cases like a stone protocol CT where we know we are not going to need it, everybody gets a creatinine.

FISHMAN: What if a patient doesn't have a creatine level? What do you do?

ZALIS: The scans are often protocoled a day or more in advance. Aside from an acute situation in which there's an overwhelming need to get the scan right then, basically we try to catch the problem early. If they are in an acute care situation, we can usually get the lab done quickly.

WHITE: Yes, we do it too, although we'll accept a creatinine done in the past month or so.

FISHMAN: Our issue is kind of a practical one. Half of our patients are added to the CT schedule on the same day, so we don't have the luxury of doing things in advance. We actually

wanted to do the instant creatinine, but I guess maybe you're in an outpatient center. If we do it at Hopkins, it means we're a lab and we have to be certified as a lab. Nothing is as simple as you think it is, right?

At Hopkins, if I have to send a patient downstairs to get a creatinine, it could be 4 hours before they return. So it is just an unworkable situation.

We try more and more, somewhat successfully, especially on cases in which we can ask for creatines in advance. But there's no real standard of care at this point for what you need to do and when you need to do it.

The largest article published echoes the two comments you made regarding the risk in patients with diabetes and renal disease based on the patient's history. In those patients, having a creatinine is mandatory. I think it is a little bit easier these days with 64-slice CT because your contrast volumes are lower. Now we just use iso-osmolar contrast media and reduce the volume a bit. But that alone is probably not the right answer either.

ZALIS: I would like to ask a question that follows up on something that Dr. Federle said. I have a growing interest in having an intelligent search of the medical record. We're also very much involved in developing machine learning-based oncology systems for exactly that kind of problem. How long is fast enough to get a specific piece of information from the medical record while you are in the midst of a busy day interpreting studies?

EARLS: Do you mean 1 piece of information or the entire clinical picture?

ZALIS: Let's say you're reading a CT scan and you want to know a specific thing, such as "Does this patient have a positive PPD?" or "Was there history of a particular kind of infection?" You need to find a specific needle in the haystack of the patient's medical record.

FEDERLE: We can do it quite quickly at our place, depending on who is doing the searching. I am one of the few people around here who still does fluoroscopy.

It's funny, I will see my residents spend 15 minutes going through the electronic medical record for a postop patient. I'll ask them, "What are you looking for in there? This patient speaks English. Go in and ask them what they had done." If you need to check the record, it ought to be a 20-second thing. It's like the Google phenomenon. You think you are looking for a piece of information, and the next thing you know, they are going off on all these wild tangents. So my answer to your question is that it usually takes me roughly 10 seconds to find what I'm looking for. It takes a first-year resident about 10 minutes to find what I want them to look for. They often uncover all sorts of other useless information, but our system works remarkably well.

ZALIS: So the 10 seconds is based on your personal interaction with your typical fluoroscopy patient?

FEDERLE: No, that's even for CT. I mean, 10 seconds is an exaggeration. But it might be something as simple as realizing that the patient has only 1 kidney. The referring doctor didn't tell me why the patient has only 1 kidney, but I can click on our medical archival and retrieval system quickly to find the surgical pathology or surgery record. If the patient had a nephrectomy and the surgical pathology revealed renal cell carcinoma, I have the answer. I'm kind of surprised that wasn't given to me in the patient history.

EARLS: I actually think the answer is that it's never fast enough. When you buy a new PC, it's fast enough for about a week. Then you start thinking that it should be faster. So as soon as we get it, if it's 30 seconds, that would be great for a short period of time. Then it should be 15 seconds, and then it should be 5 seconds.

FISHMAN: DeAnn, I know you are not a clinician, but what is your perspective?

HAAS: I don't have a lot of experience with medical records. But I agree with you that it's never fast enough. It's the same phenomenon with the workstations. You click on something and you wait. When you get the next version of a computer, it's roughly 10 seconds faster. So we need it as fast as we can get it, and as physicians, your time is demanding. You need to speed up anything that we can do.

WHITE: I get very impatient. We have a search tool through our information system, and it's actually good for case reports and things like that. You can get all your thymomas or whatever. But the reality is, on a day-to-day basis, if I can't find it within 30 seconds, I'm going to send a resident off, and maybe they will go find it. But that's it for me, as far as I'm concerned.

FISHMAN: I'm into telepathy—anything beyond that is probably too long!

You're right, you can look at most information in 10 seconds. Sometimes residents and fellows spend 20 minutes looking for everything except what they actually need to find. So then they are looking at fewer cases than ever. Residents may be looking at 10 cases a day, but they know every bit of history about each patient. They are so caught up in the information that they are spending 2 minutes looking at a case and they're missing what was there on the image. But they know that the patient had an appendectomy at age 9. Since the patient is 87 now, that is probably just not that critical.

New developments in cardiac gating

Today, most cardiac CT studies use multidetector helical acquisitions and retrospective gating. New approaches to prospective triggering may change that picture.

James P. Earls, MD

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Electrocardiographic gating is an essential component of cardiac computed tomography (CT). By permitting synchronization with the electrocardiogram (ECG), gating enables the user to specify data acquisition and image reconstruction at a specific point in the cardiac cycle, both optimizing image quality and defining the type of information available to the clinician.

This article will review retrospective gating methods commonly used in coronary CT angiography (CTA) today, as well as new multiphase adaptive prospective gating techniques. It will also discuss image quality, reliability, radiation dose, radiation risks, patient selection, and limitations associated with cardiac gating techniques.

Current gating methods

There are 2 key requirements for coronary CTA. One is high spatial resolution, which enables visualization of small arteries and small plaques and depiction of complex cardiac anatomy. The other is high temporal resolution, which eliminates the motion artifact associated with the beating heart, makes it possible to image the entire heart volume in a single breath-hold, and enables resolution of individual coronary phases.

Initially, when cardiac CT was performed primarily on electron-beam scanners, data were acquired with prospective ECG triggering. The optimal phase for data acquisition was determined empirically using a scan delay based on the R-wave peak. This entailed either an absolute delay or a relative delay expressed as a percentage of the R-R interval.

One problem with this early approach to prospective triggering was that it required many steps in order to cover the anatomy, because it was accomplished with either a single detector or a small number of detector rows. For example, using a 16-slice multidetector scanner and a collimation of 0.625 mm, it would take 14 individual steps to cover 140 mm of cardiac anatomy. Furthermore, in order to facilitate table movement, it would be necessary to acquire data on every second heartbeat. At 60 bpm, this would result in a 28-second acquisition time, which is far longer than optimal. Additional problems with early forms of prospective triggering included the inability to adapt to changes in the R-R interval, the potential for gaps in coverage as a result of ectopy, and the ability to acquire only a single cardiac phase.

More recently, the vast majority of cardiac CT examinations have been performed on multislice CT scanners with retrospective gating. The heart is covered continuously in a single spiral scan, with simultaneous recording of the ECG and data acquisition during all cardiac phases. A pitch <1 produces multiple overlapping areas of acquisition. Together, these features make it possible to use retrospective gating to select multiple cardiac phases and reconstruct data in any phase.

A strength of retrospectively gated helical (RGH) CT is that it is possible to take data from a specific point in the cardiac cycle in order to generate an image during diastole or to select data from a different point in the cardiac cycle to generate an image during systole, if desired. This flexibility is useful because individual coronary arteries may be optimally visualized in different phases of the cardiac cycle. Specifically, the right coronary artery (RCA) is sometimes best seen in late systole, whereas other coronary arteries are best seen in diastole. Retrospective gating also enables an evaluation of cardiac function. For example, reconstructing throughout the cardiac cycle permits an analysis of both global and regional wall motion for areas of dyskinesis or hypokinesis.

A limitation of RGH CT is the need to use a very low pitch (approximately 0.2 to 0.4) to avoid gaps in anatomic coverage. This means, however, that each anatomic area of the heart may be scanned 4 or 5 times during data acquisition, which results in a relatively high radiation dose. The desire to minimize radiation dose, and the realization that information acquired during the systolic phase often goes unused, led to the concept of ECG dose modulation. Lowering the tube current during most of the systolic phase results in approximately a 30% to 40% reduction in overall radiation dose.

Retrospective gating with ECG dose modulation relies on the assumption that the patient is in normal sinus rhythm with a stable R-R interval. If the patient

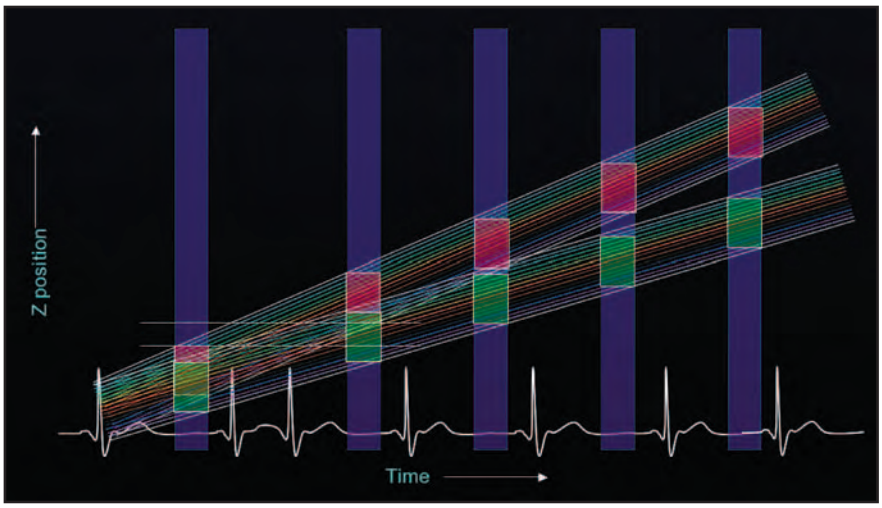

FIGURE 1. *A reconstruction of retrospectively gated helical CT relies on the patient's being in normal sinus rhythm with a stable R-R interval. A shortened R-R interval may cause data acquisition to occur during an undesirable phase of the cardiac cycle. Discarding such data could result in coverage gaps (the space between the first 2 pink reconstruction windows). The use of an even lower pitch ensures overlapping areas of coverage (green reconstruction boxes).*

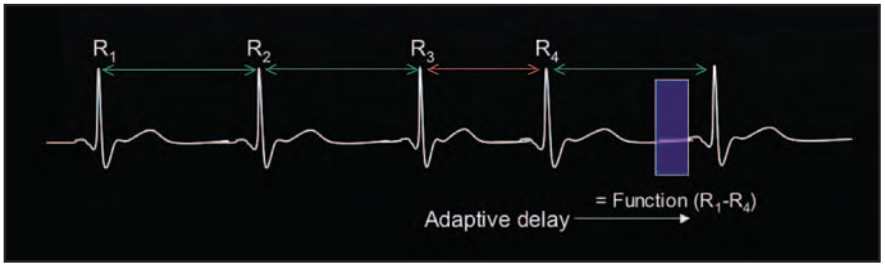

FIGURE 2. *In a patient with significant shortening of the R-R interval, an adaptive delay triggers the scan on the basis of multiple previous R-R intervals, which is more likely to result in an optimally timed acquisition. The weighted delay changes from beat to beat.*

develops arrhythmia during the scan, data acquisition may occur during an undesirable phase of the cardiac cycle. Discarding that data could result in coverage gaps unless an even lower pitch—often approaching 0.2, depending on heart rate—is used to ensure overlapping areas of coverage (Figure 1).

It is informative to look at radiation dose from a historical perspective. Initially, before 16-slice scanners were equipped with ECG dose modulation, the effective radiation dose to the patient averaged approximately 10 to 12 mSv. Once ECG modulation was introduced, the radiation dose associated with a 16-slice scanner dropped to approximately 5 mSv. This is equivalent to the average dose reported for diagnostic cardiac catheterization.

When 64-slice technology was introduced, reported radiation doses increased to 10 to 20 mSv, even with ECG modulation. With a faster rotation speed and shorter acquisition time, the 64-slice scanner necessitates the use of a higher mA to deliver the same photon flux into the image. An increased tube current is also needed to maintain photon flux as a result of thinner collimation. The net result is an increase in the radiation dose to the patient. New dual-source CT has reduced radiation dose somewhat, to approximately 13 mSv, but it remains considerably higher than that of 16-slice CT with ECG dose modulation.[1-10]

Multiphase adaptive prospectively gated axial CT

Radiation dose was a key factor in prompting reconsideration of prospective triggering. Also called multiphase adaptive prospectively gated axial (PGA) CT, this new version of prospective triggering has been modified to overcome certain limitations of the earlier version. An adaptive scan delay is one of the improvements. Rather than using a fixed delay after the R-wave peak to determine when to turn the tube current on, the scan now starts with an adaptive delay that is a function of multiple prior cardiac cycles. The adaptive delay, which changes from beat to beat, determines where in the cardiac cycle the acquisition will take place.

As shown in Figure 2, an adaptive delay may not differ greatly from a fixed delay in patients with a steady R-R interval. However, in a patient with significant shortening of the R-R interval, an adaptive delay will trigger the scan on the basis of multiple previous R-R intervals, which is more likely to result in an optimally timed acquisition.

The ability to acquire limited multiphase data sets through "padding" of the X-ray tube's on-time is another improvement. This means that rather than turning on the tube current for approximately 185 msec during diastole and acquiring a single image—the typical perception of prospective triggering—the tube is turned on a little earlier and left on a little later to generate data from additional phases. By turning the X-ray tube on for an additional 25 to 200 msec, it is possible to capture data from 10% to 25% of the cardiac cycle on either side of the optimal phase.

More optimal visualization of the RCA is a potential advantage of acquiring limited multiphase data sets. If motion artifact is evident in one phase, it may be possible to reconstruct in another phase. Padding of the tube on-time does not, however, permit the analysis of quantitative or even qualitative regional or global myocardial function.

A new reconstruction algorithm that improves image quality is the third improvement associated with multiphase adaptive PGA CT.[11] With helical CT examinations, certain areas of the reconstructed volume are undersampled as the result of cone-beam geometry and the use of half-scan acquisitions, rather than full 360° acquisitions. Interpolation can lead to degradation of image quality.

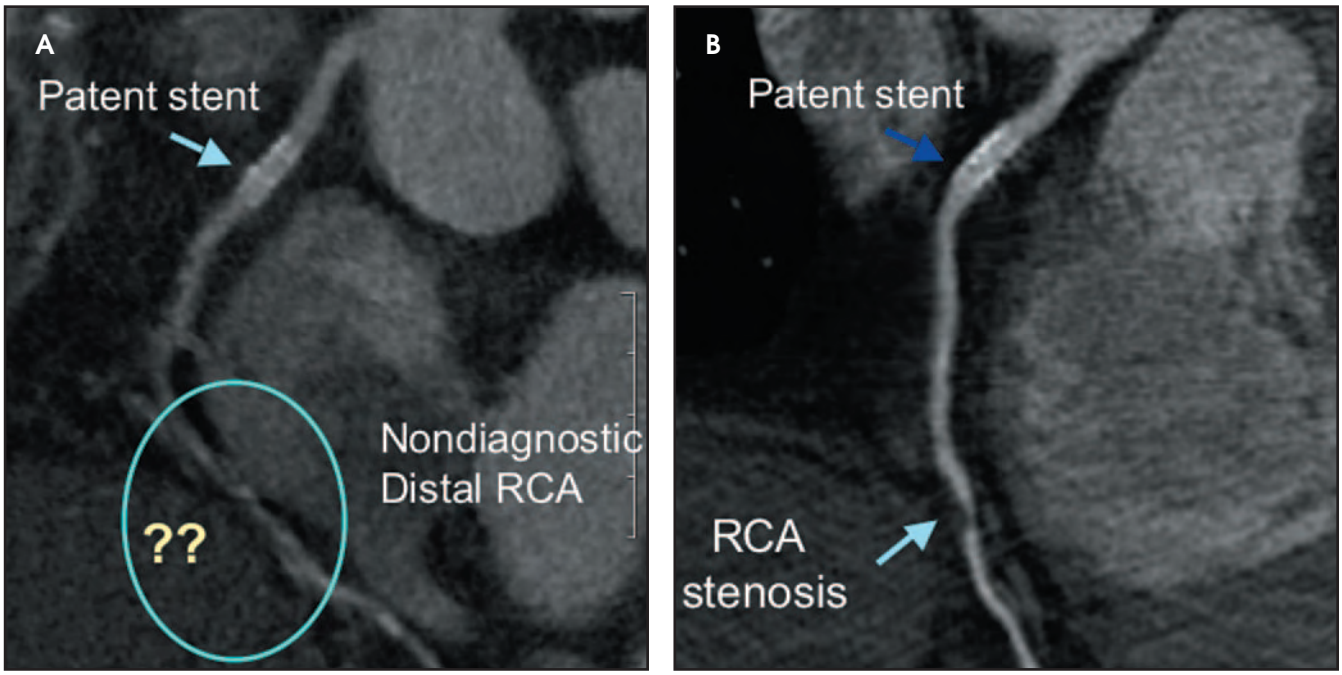

FIGURE 3. *A 52-year-old woman with a previous implantation of a drug-eluting stent in the right coronary artery (RCA) and new-onset chest pain. With a height of 5 feet and a weight 200 pounds, her body mass index was 39. (A) Retrospectively gated helical CT coronary angiography revealed a patent stent in the proximal RCA (arrow); however, motion artifact prevented resolution of the distal RCA, despite image reconstruction in multiple phases. Because of the patient's obesity, 730 mA was used during the scan, with a resulting radiation dose of 23 mSv. (B) A repeat scan using prospectively gated axial CT showed not only a patent proximal RCA (dark blue arrow), but also significant stenosis in the mid-to-distal RCA (light blue arrow). The radiation dose for the second scan was just 3.9 mSv.*

A new gated complementary reconstruction algorithm helps to correct for this limitation by making use of complementary samples from adjacent scans.

A study by Shreter et al[12] using phantom models showed that the use of PGA CTA with approximately 10% phase padding and the new reconstruction algorithm improved z-slice sensitivity by 6% and in-plane resolution by 8% when compared with conventional RGH CTA. It also reduced the radiation dose by 70%. Contrast detectability was approximately equivalent.

Image quality and reliability

Our group recently evaluated the new prospective triggering technique in a clinical setting.[13] The purpose of the study was to compare the radiation dose, image quality, coronary artery assessability, and reliability of multiphase adaptive PGA coronary CTA with that of RGH coronary CTA.

Using a 64-detector row CT scanner, we first evaluated 82 patients using RGH CT with ECG dose modulation. We then scanned 40 patients using the new PGA CT software; data from this learning phase were disregarded. Data gathered from the next 121 clinical patients who were scanned with PGA CT software were included in the final analysis.

The 2 study groups were well matched in gender, age, body mass index (BMI), heart rate, and clinical indications for the study. Three readers who were experienced in interpreting 500 to 3000 coronary CTA studies and who were blinded to the scan technique evaluated image quality in the left main, left anterior descending, left circumflex, and right coronary arteries, using a standard image quality scale.[14,15]

Our initial hypothesis was that image quality would be equivalent with the 2 techniques. Instead we found that multiphase adaptive PGA techniques improved image quality overall as well as for each of the coronary arteries individually. It must be noted that image quality was excellent in both groups, however, with a mean score of approximately 4.79 for the PGA group and 4.54 for the RGH group on a scale of 1 to 5 (P <0.001). Still, the small differences we observed between the 2 groups were statistically significant.

Differences in image quality can be clinically important as well. Figure 3 shows a 52-year-old woman who had undergone implantation of a drug-eluting stent in the right coronary artery and later developed new chest pain. At 5 feet tall and 200 pounds, her BMI was 39. Retrospectively gated helical coronary CTA showed a patent stent in the proximal RCA; however, motion artifact prevented resolution of the distal RCA, despite image reconstruction in multiple phases. Because of the patient's obesity, a high mA was used during the scan, (730 mA), resulting in a radiation dose of 23 mSv.

A few days later, the patient underwent a repeat scan. The second examination, which was performed with PGA coronary CTA, showed not only a patent proximal RCA but also significant stenosis in the mid-to-distal RCA. Equally important, the radiation dose

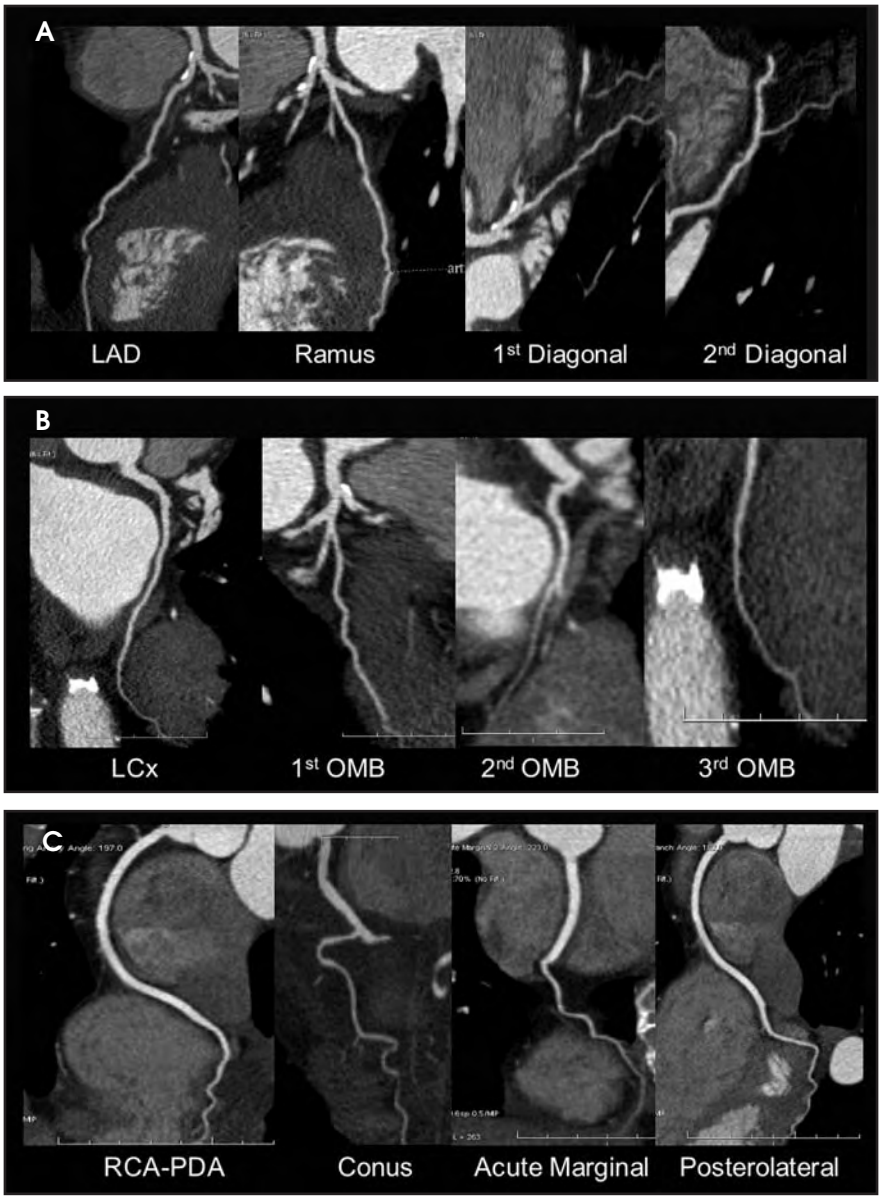

FIGURE 4. *A 76-year-old man was found on thallium myocardial perfusion imaging to have an inferior perfusion defect (not shown). Coronary CT angiography revealed mild diffuse nonobstructive coronary artery disease. Using prospectively gated axial CT techniques, assessability is high in all coronary arteries. (A) The left anterior descending [LAD] coronary artery, including the ramus and the first and second diagonal branches. (B) Left circumflex [LCx], including the first, second, and third obtuse marginal branches [OMB]. (C) Right coronary artery [RCA] and posterior descending (coronary) artery [PDA], including the conus, and acute marginal and posterior lateral branches. The effective radiation dose was 0.95 mSv.*

for the second scan was just 3.9 mSv using 800 mA.

This case illustrates an important point about the assessability of the RCA, which was confirmed on further analysis of our study data. The RCA is typically the most difficult artery to visualize on RGH coronary CTA; therefore, it is often necessary to reconstruct images using data from late systole.[16] As those phases are not available when PGA CT techniques are used, we were concerned about the assessability of the RCA using prospective triggering. In reality, we found no significant difference between PGA CT and RGH CT in the assessability of the 3 RCA segments (96.7% versus 98.1%, respectively). In addition, the average image quality of the RCA was significantly higher for PGA CT than for RGH CT (4.62 versus 4.45, $P < 0.01$).

Prospective gating yields equally impressive results in the other coronary vessels (Figure 4). Overall, we found that accessibility was approximately 97% with both PGA CT and RGH CT. Reliability, as gauged by the percent of diagnostic studies, was also equivalent (98.3% versus 98.7%, respectively).[13]

Radiation dose and risks

The terminology used to describe the radiation dose and the units of measure have changed in the last few years. The volume CT dose index ($CTDI_{vol}$) describes the absorbed radiation dose and is measured in grays (Gy). The dose length product (DLP) describes the cumulative radiation dose. It is akin to the absorbed dose integrated over a volume and is measured in mGy × cm. The effective dose (E) describes the biological effect of the radiation dose. It is determined by both the absorption and susceptibility of various organs in the field of view and is measured in sieverts (Sv).

The phantom study by Shreter et al[12] found that the reduction in radiation dose with PGA CT depended on the degree to which the X-ray tube on-time was padded. For example, when the tube on-time was increased by 10% before and after the minimum necessary acquisition, the radiation dose with PGA CT was reduced by 56% when compared with RGH CT. With moderate phase padding (5% before and after the minimum acquisition time), the radiation dose was reduced by 68%. With no phase padding, the radiation dose was reduced by approximately 80%.

In our clinical study, the effective radiation dose associated with RGH coronary CTA ranged from approximately 7 mSv in the smallest patients to 23 mSv in the largest, with a mean of 18.4 mSv.[13] The effective dose was reduced to a mean of 2.84 mSv in the comparison group of 121 patients scanned using the new PGA CT software. We noted similar reductions in $CTDI_{vol}$ (mean, 81%) and

Table 1. Cancer risk following multiple cardiac imaging studies*

Scan type	Technique	Effective dose	Risk 1 exam	Risk 5 exams	Risk 10 exams
TI-201	Stress/rest	25 mSv	1/400	1/80	1/40
DSCT	Helical/ECG-modulated	13.2 mSv	1/756	1/151	1/76
64-row MDCT	Helical/ECG-modulated	12 mSv	1/833	1/167	1/83
MIBI	Stress/rest	12 mSv	1/833	1/167	1/83
16-row MDCT	Helical/ECG-modulated	5.15 mSv	1/1942	1/388	1/194
64-row MDCT	Prospective axial	2.8 mSv	1/3571	1/714	1/357

*Risk estimates are based on the data in the BEIR VII Report: 10 mSv dose = 1/1000 lifetime cancer risk.[17]
TI-201 = thallium-201 scan; DSCT = dual-source computed tomography (CT); MDCT = multidetector CT; ECG = electrocardiographic.

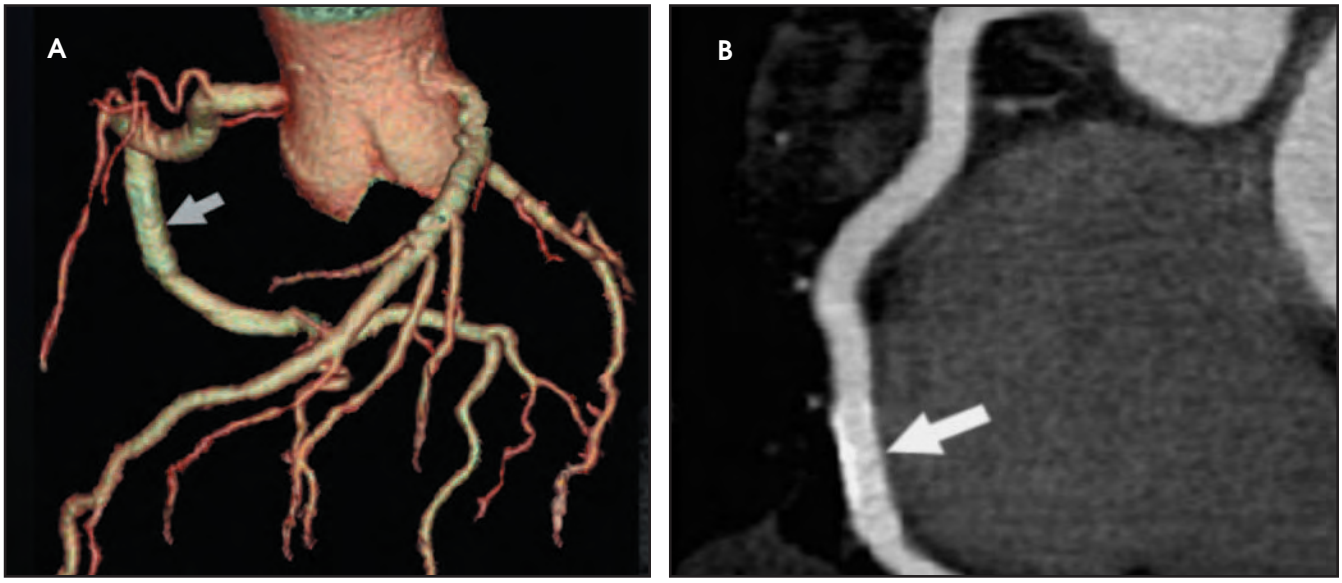

FIGURE 5. *A 55-year-old man with a 3-year-old right coronary artery (RCA) stent and new chest pain. (A) A volume-rendered image of the coronary tree depicts the stent (arrow). (B) A curved multiplanar reformatted image of the RCA depicts a widely patent 3.0-mm drug-eluting stent (arrow). The CTA effective dose using prospectively gated axial (PGA) technique was 0.90 mSv.*

dose length product (mean, 84%). In small patients, it is possible to reduce the effective radiation dose to <1 mSv using PGA CT techniques.

The relationship between the absorbed radiation dose and the risk of fatal cancer is the subject of intense discussion. According to the Biological Effects of Ionizing Radiation (BEIR) VII study,[17] a single 10-mSv effective dose confers approximately a 1 in 1000 lifetime risk of developing a fatal cancer. Both the U.S. Food and Drug Administration (FDA)[18] and the International Commission on Radiologic Protection[19] have placed the risk at about half that level, or approximately 1 in 2000. The correct answer may lie somewhere in between.

To keep the issue of radiation exposure in perspective, it is instructive to compare coronary CTA with other more commonly performed cardiac imaging studies. A diagnostic cardiac catheterization exposes the patient to 5 mSv, while technetium-99m sestamibi nuclear studies expose the patient to 12 to 17 mSv, depending on the specific imaging protocol. A thallium-201 stress/reinjection examination exposes the patient to 25 mSv, and a dual-isotope examination exposes the patient to 27 mSv.[20]

At approximately 5.2 mSv, the effective radiation dose from a 16-slice helical scan with ECG dose modulation is much lower (Table 1). A 64-slice scan, when used in helical mode with ECG dose modulation, comes in at approximately 12 mSv, and when used in prospective triggering mode, at just 2.8 mSv.

Based on data from the BEIR VII report, the lifetime risk of fatal cancer associated with a single 25-mSv thallium examination would be 1 in 400.[17] The lifetime cancer risk associated with a single 64-slice RGH CT examination (12 mSv) would be approximately 1 in 800, and with a single 16-slice RGH CT examination (5.2 mSv) approximately 1 in 1900. The risk drops to approximately 1 in 3600 for a 64-slice PGA CT examination (2.8 mSv).

The reality, however, is that virtually no cardiac patient undergoes just one imaging study. In fact, patients with long-standing cardiac disease who have had stenting or bypass surgery often undergo ≥10 nuclear and other imaging studies over a number of years, during the prolonged course of this disease.

The cumulative radiation dose associated with repeated cardiac studies can be substantial. For example, 5 thallium scans would increase the lifetime risk of fatal cancer to 1 in 80, according to the

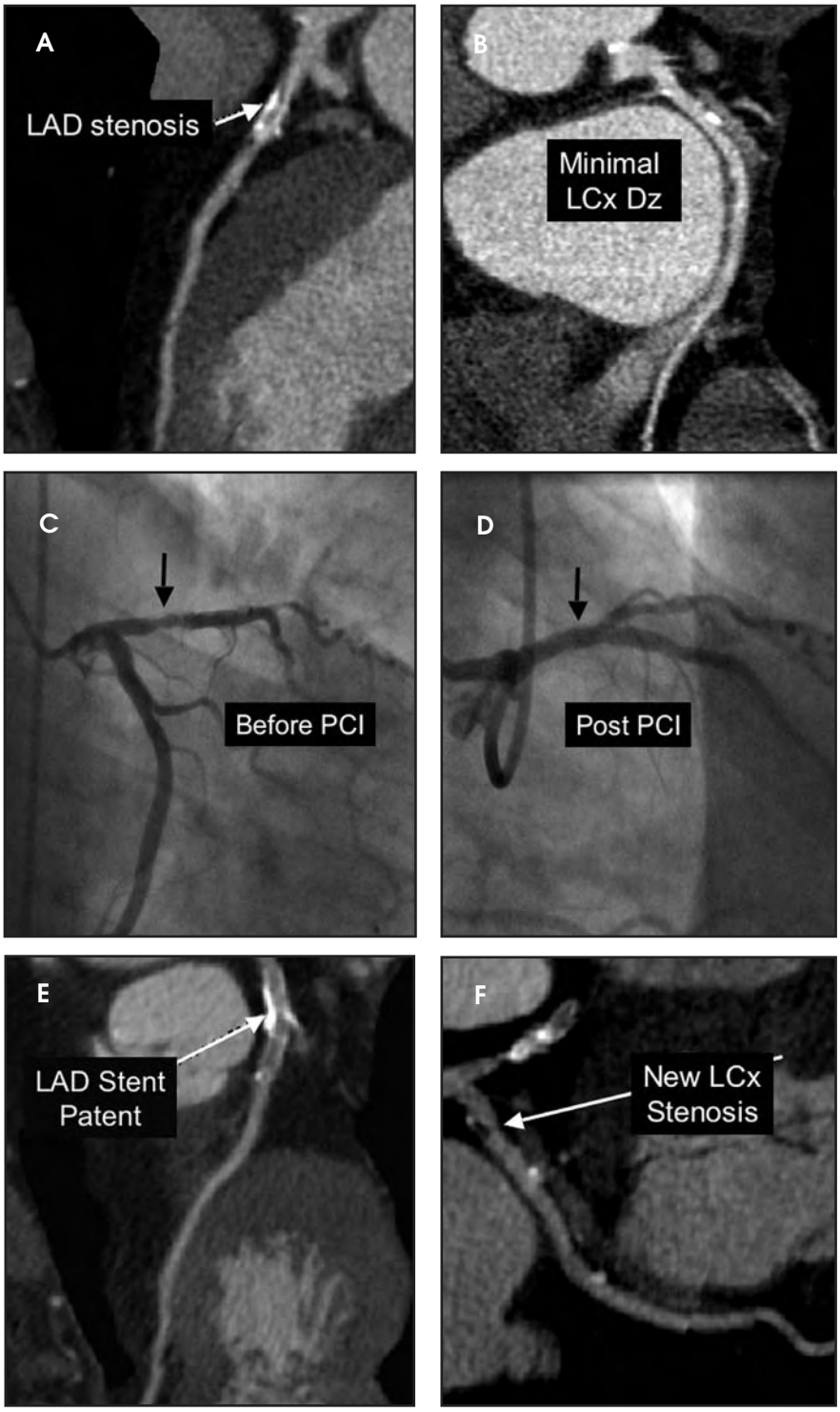

FIGURE 6. *A retrospectively gated helical coronary CT angiogram (CTA) performed on a 76-year-old man with chest pain. (A) A curved planar reformatted image revealed an 80% stenosis of the left anterior descending artery [LAD] (arrows) and (B) a patent left circumflex [LCx]. (C) During conventional angiography, the LAD stenosis (arrow) appeared smaller than it did on the coronary CTA (shown in A), but its severity was confirmed by intravascular ultrasound (not shown). (D) The patient was treated successfully with percutaneous coronary intervention [PCI] and the placement of a stent (arrow). Six months later, the patient developed syncope. (E) A prospectively gated axial coronary CTA showed the stent to be patent (arrow), but (F) revealed a new focal stenosis of the LCx (arrow).*

BEIR VII data, and 10 scans would increase the risk to 1 in 40.[17] That equates to 2.5% lifetime risk of fatal cancer. If data from the FDA and the ICRP are used, the estimated lifetime risk of fatal cancer associated with repeated imaging studies would be cut in half but would remain substantial.

Even when using techniques to minimize radiation dose during the angiographic acquisition, it is important to be mindful of other potential sources of radiation exposure. For example, adding coronary calcium scoring to the protocol adds 1 to 8 mSv, depending on the specific technique. In addition, determining the scan delay through the use of a timing bolus adds approximately 0.9 mSv to the total radiation dose.

Patient selection

Heart rate is a key criterion in patient selection for PGA coronary CTA. If the heart rate remains >70 bpm despite beta blockade, PGA CT is not recommended. Substantial R-R variability is another relative contraindication.

Overall, however, PGA CT techniques can be used in nearly all patients. As of April 2007, 906 patients had come to our institution for coronary CTA; we were able to perform PGA CT in 854 (94%). A heart rate >70 bpm was the most common reason for exclusion (in 45 patients). The mean effective radiation dose was 2.6 mSv. Tube on-time averaged just 0.9 seconds.[21]

Perhaps the most common reason for performing PGA coronary CTA at our institution is the need to clarify equivocal nuclear studies. Reversible perfusion defects are observed in up to 27% of patients with angina who have normal findings on conventional coronary angiography.[22] Whether such perfusion defects represent false-positives caused by artifacts or true flow abnormalities is the subject of debate. Coronary CTA, particularly when coupled with coronary calcium scoring, can answer that question in many patients.

Prospective triggering works well for the follow-up of patients who have undergone coronary artery stenting. The improved image quality of prospectively gated coronary CTA studies is helpful in

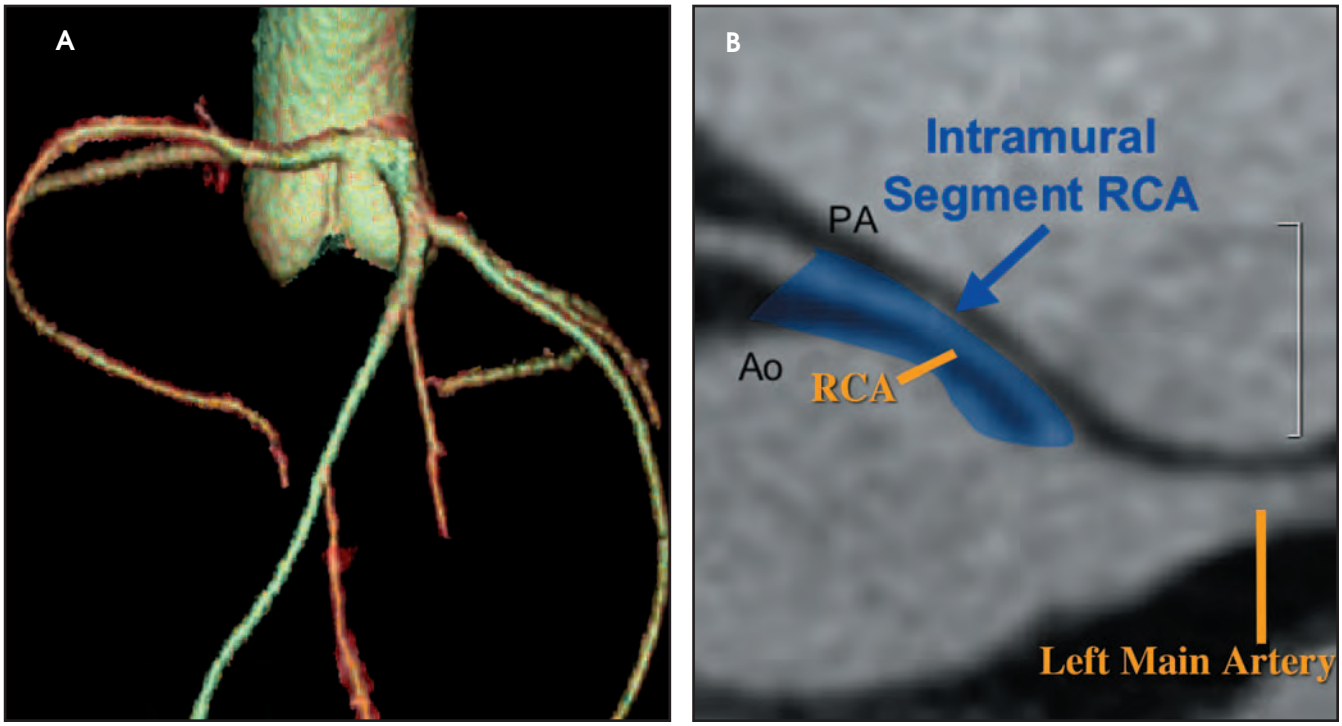

FIGURE 7. *An 11-year-old boy with chest pain after exercise and negative findings on magnetic resonance imaging. (A) A prospectively gated axial CT coronary angiography revealed an anomalous right coronary artery [RCA] arising from the left sinus of Valsalva. (B) An axial reformatted image reveals that the vessel takes an interarterial course between the aorta [Ao] and the pulmonary artery [PA]. Surgical exploration prior to reimplantation revealed that the proximal 20 mm of the RCA ran within the layers of the aortic wall (blue shaded area).*

the evaluation of coronary stent patency, as depicted in an analysis of the 3.0 drug-eluting RCA stent shown in Figure 5.

It is important to evaluate the entire coronary system in a patient with coronary artery disease, not just a stent or a bypass graft. With this chronic condition, new disease often develops over time. Figure 6 shows a 76-year-old man with chest pain who had no evidence of ischemia on myocardial perfusion imaging. Conventional RGH coronary CTA revealed an 80% stenosis of the LAD, which was confirmed by intravascular ultrasound. The patient was treated with stenting. Six months later, he developed syncope. Prospectively gated axial coronary CTA showed the stent to be patent but revealed a new focal stenosis of the left circumflex coronary artery.

We frequently use PGA CTA for the evaluation of patients with coronary artery bypass grafts. With the 64-slice scanner, we are able to do a more comprehensive examination than was possible with the 16-slice scanner, evaluating internal mammary grafts, vein grafts, and native coronary arteries, as well as anatomy beyond the heart. In an unpublished comparison of 17 post-bypass patients who were evaluated with RGH CT and 34 patients who were evaluated with PGA CT, we found that mean effective radiation doses were 31.3 and 5.0 mSv, respectively (unpublished data, 2007).

As mentioned earlier, PGA CT techniques enable the acquisition of high-quality images in obese patients. Because the tube on-time is <1 second for each acquisition, it is possible to safely use an mA of 800. The images are typically noisier than those acquired in a normal-weight patient, but they are of diagnostic quality.

Prospective triggering is ideal for the evaluation of coronary anomalies as well, particularly in children. Figure 7 shows an 11-year-old boy who had been experiencing chest pain after exercise. Cardiac magnetic resonance imaging showed no abnormalities, but PGA coronary CTA revealed an anomalous right coronary artery arising from the left sinus of Valsalva.

Other applications of PGA CTA include pulmonary vein mapping in preparation for ablation of cardiac arrhythmias, evaluation of coronary artery dissection, follow-up of pediatric patients with Kawasaki disease and other abnormalities that require ongoing surveillance, and gated aortic studies.

Conclusion

Retrospectively gated helical techniques currently dominate clinical CTA. This approach yields high-quality images and has the added advantage of providing information from multiple cardiac phases. However, a new technique, multi-phase adaptive prospectively gated axial CTA, is reliable and robust. Roughly 97% of examinations are diagnostic, and 97% of coronary segments are assessable. At the same time, PGA CTA enables a significant reduction in radiation dose—83% when compared with RGH CTA. Finally, image quality is at least as good with PGA CT as with RGH CT and may be even slightly better.

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Discussion

ELLIOT K. FISHMAN, MD: We have to balance the need for information on coronary disease we can get from CT with the concern regarding the radiation dose.

JAMES P. EARLS, MD: Radiation dose is a consideration with coronary CT. An individual's risk of developing a radiation-induced cancer decreases as one gets older because there is less lag time for one to develop. It may take 20 years or more for a cancer to develop. If you are 70 with coronary disease, you may not live the 20 years for the cancer to become apparent when you are 90. But if you are 45, then you probably do have that risk.

MICHAEL E. ZALIS, MD: The radiation risk that you were describing, is that an average risk? Do you know what that average was you were using for those numbers?

EARLS: The studies I was quoting would also usually give a range. They would cite the male effective dose and the female effective dose. I actually just took a median of the 2 numbers quoted in the papers as the average doses.

FISHMAN: Let me ask a different question. I've noticed that at meetings, even at dedicated cardiac meetings, if you ask the audience, "How many of you are actually doing cardiac CT?" you only get 10% to 20% positive response. I would say the same is true with virtual colonoscopy—only roughly 10% of the audience are doing virtual colonoscopy. These are people who already have the equipment. They may even have a 64-slice scanner. You can show very nice images, and the published results are excellent. What are the barriers that keep people from doing it?

EARLS: I still have people come on site visits and then they buy scanners. I run into them at a meeting a year later, and they tell me, "We love it, but we just haven't gotten it going." They are afraid of it. Part of the problem is that we don't get a lot of training in cardiovascular diseases in radiology. It's changing more now, but for a long time that was just the black hole in the middle of the chest. Because I was in academics, I developed an interest in it and was able to continue it in private practice. I think that focus is finally changing now.

You've really got to be on top of your game in knowing how to use the scanner and knowing how to use the 3D processing capabilities. That's a lot of extra effort for people who are really busy doing sterotactic breast biopsies and barium enemas at the same time. So I think that prevents a lot of people who are doing general radiology from getting involved in it in a more focused manner. The other part is that the reimbursement piece isn't there. I had to really force my practice to get this program up and running to the extent that we have. Everybody has the arguments: one, there's no reimbursement so you will lose money. Two, by the time there is reimbursement, cardiology will steal it away and there will be nothing for you to do. So some people believe it's a complete waste of time and effort, but I don't believe that is true. But those are all barriers that people are up against when they try to start.

CHARLES WHITE, MD: He's covered many important points. One

additional point is that in a lot of training programs, even to this day, there aren't teachers to teach this stuff. So when residents come out, even if they were potentially interested, they have not had the mentorship. Perhaps that's changing; obviously one of the goals of fellowships is to make a change.

The other point is the mental block about cardiac imaging. It is actually honestly more of a psychological issue than a real issue because I think cardiac is actually fairly straightforward to learn. It's probably much more straightforward to learn than some of the things that we learned that took an awful lot of time. I always say there are only 3 coronary arteries, although clearly it's a little bit more complicated than that. But, in a sense, there are 3 coronary arteries and 1 disease. Granted, there are a lot of nuances, but at its most basic, that's what it is.

So we have to get over the psychological barriers. Then we have to train enough people who are obviously busy with other very legitimate activities to do this as well.

FISHMAN: Do you think the fear is on the acquisition side, in acquiring the data set and scanning the patient, or on the postprocessing side?

WHITE: I think it's both to some extent, but more so on the interpretation side.

EARLS: There is the third issue, which is that you have to do your interpretation and put your diagnosis out to a bunch of cardiologists, who do this all the time.

WHITE: It's important to have that feedback, as you showed with the catheter, when the cath results come back and it doesn't totally agree with your interpretation. Now, cath has its own limitations—it's laminography. In many cases, CTA is the right answer. But, because CTA is much newer, the perception right now is that catheterization is the gold standard. Well, that's not always the case. So when you have to take that to radiologists who are less familiar with cath to begin with, there is a certain level of intimidation that must be overcome.

FISHMAN: I also don't think radiologists are getting the demand for it. Radiologists often do what they are asked to do. At Hopkins this week, they are having a course called "Topics in Internal Medicine" given to internists and general practitioners, roughly 500 GPs, and I gave a talk in cardiac CT. The first thing I asked of these 500 people was, "How many of you have ever ordered a cardiac CT?" I would say only 20 people raised their hands, at most.

Radiologists often tend to do what people bother them to do. Right now, there are not a whole lot of people rushing to you for this. A lot of people know about it; it seems to me more laypeople know about it than referring physicians if that is humanly possible. Because it's hard to read a mass media publication these days—I don't mean *New England Journal of Medicine*—I mean *Time* magazine or *Newsweek*, that doesn't have some article on cardiac CT.

DEANN HAAS: It was on Oprah. Oprah has the biggest media power with females, and it's an afternoon show. They are going to tell their husbands to go in and have this test or go request this test. She is one of the biggest influences. When her first show came about the sites that were doing CT, they got a huge influx of patients coming into them.

ZALIS: It's the same exposure with Katie Couric on colon screening.

WHITE: It is a challenge of its own to make your fellow radiologists comfortable with going forward with a cardiac CT program. Your comment about having relatively few people raise their hands when asked if they would have cardiac CT is a strong indication that a lot of people are confused about it, although they may or may not have seen the pretty pictures. They are certainly confused about what the appropriate indications are and when they should use it.

If you are going to start a program, one of the key things is that you have to educate. There are other tests that are well established—stress testing, cath, and echo—which are to some degrees competing. So where does cardiac CT actually fit in? I think those of us who do it quite a lot have some opinions and some real sense of what that answer might be. But we need to do a better job of communicating that, so that the outside referrers who potentially could benefit from this will go ahead and use it.

FISHMAN: Jay, with all this prospective gating, how much of that is machine-specific? If I don't have a GE scanner, can I go and do it?

EARLS: We have had a beta version of prospective triggering from GE since September 2006. It was available clinically as of June 2007. Phillips announced their version at RSNA 2007, but I believe they are still beta testing their version in a limited number of evaluation sites. Both Toshiba and Siemens have stated that they were working on versions, but I have not seen any clinical data as of yet.

WHITE: To my knowledge, Jay's comments are about the state of the art. Philips has a version that's been beta tested. We are a Philips site; so we have used it a little bit and had some nice early results. We have not had the kind of extensive experience that he described, though. Part of the key to making it work is having a long Z-axis. In other words, you were talking about roughly 3.24 cm, and that is advantageous to a step-and-shoot type of approach. So configurations that are in that direction tend to be a little more easily applied. That's not to say that it can't be done in other configurations. That is part of the reason I think those 2 vendors are at the head of the game.

HAAS: I think you can use the calcium scoring technique. The difference when we did the calcium scoring was that your interscan delay was longer. It's not that we didn't care, but it was just a longer scan in general. You took an image, waited about 1.5 seconds, and you took another image. We have decreased that interscan time delay, so it's in a manageable breath-hold again. With the wider detector, you don't ever want to go back to a 20-second scan. That's when we didn't get the reproducibility that we get now with the 64-channel detectors.

EARLS: Our actual acquisition times are about 25% faster with prospective triggering than they are with retrospective triggering.

ZALIS: I have a question concerning an increasing number of slices and the practical impact on the particular exam. For the colon, I think there's a growing consensus that once you reach 16 channels, you are probably near a functional effective limit. At this point, nobody has really clearly shown that having a 256-channel scanner is going to significantly improve your clinical outcome of performance in the colon. What are your perspectives about that for cardiac?

EARLS: That is a big question now. Should it be more slices, more resolution, or more temporal resolution? Those are the 3 ways we can go. It's interesting that it looks like 3 vendors have each chosen a different path. I don't know if there will be 1 winner or if there will be 3 winners there.

WHITE: I would say that ultimately it may all converge. Maybe this isn't true in the colon, but certainly in the heart, it is advantageous to be able to do a whole organ scan, for things like perfusion or for decreased variability in scan acquisition. That's not to say that it isn't possible over time to get all 3: temporal resolution, spatial resolution, and whole-heart coverage. Those are all good things. Ultimately, it's a question of which technology you bring to the problem to try to solve it.

EARLS: I would take temporal and spatial resolution first. I think the problem with the whole-organ coverage is that you will come up against the radiation issue because of cone-beam geometry issues. You can scan the whole organ at one time, but the dose will be substantial. Adding additional acquisitions for perfusion and/or viability will only add additional radiation dose.

ZALIS: If I were from a more naïve, somewhat novice perspective about that domain, the sense I get is that yes, 256-channel and higher would significantly improve your ability to do the exam.

EARLS: That is the knee-jerk response. Once you are experienced with it, you realize that there are other areas. But again, I think we need results to see the effect.

MICHAEL P. FEDERLE, MD: But I do think there is an observable difference between the 16-slice and the 64-slice scanner. In CT colonography, that may not be true. But I think that the 64-slice was a substantial improvement over 16-slice for cardiac CT.

FISHMAN: For cardiac, there's no doubt. With 16-slice, you can get a few cases right some of the time. But, even in the best of hands, 70% of the cases would be done with so-so or adequate studies. Now, with 64-slice, I think we can do a really good study in 95% of the cases. Going back to the challenge people face in cardiac CT, I think part of it is the acquisition. There is no doubt people are a little bit afraid of doing the studies right.

I think the other issue is that when you read the literature, the published results are almost too good. Every article you read says 99%, but people never believe 99%. If it were 82% percent, people would believe it. Another problem with almost all of the published articles is that most of them are not very rigorous, which is always a bit surprising. What I mean by that is they don't have 3 observers. Most articles that are done in the liver use 3 observers, so, of course, they observe variability. Most of the articles published on cardiac imaging have just 1 person reading the study, never 2 people.

DeAnn and Jay both showed many different tools for cardiac imaging. The question is, how do you really read a cardiac CT? We get back to this all the time. Stephan Achenbach, who has tremendous experience, says, "I only look at the axial CTs." I give him a hard time because when he shows his lecture, he always shows 3D images. So I say, "You only look at the axials, but where do you get those 3D images?"

There's a certain way of looking at things, and people feel comfortable that they have a workflow issue. You were talking about automation, which will probably help out. So I would like to hear how people are doing it. Jay, how do you read a cardiac CT?

EARLS: I look at the axials first and probably >90% of my diagnoses I can make from the axials. Then I always go on to 3D images to show that. So, I'll read the axials, then I do a volume-rendered tree view to facilitate the next step, which is the curved reformats of each of the individual vessels. So those are the three steps that I go through in all of the studies.

FEDERLE: I don't do it, some of my colleagues do.

HAAS: I could address this from the training perspective. I've trained a lot of physicians and technologists on how to do the processing. At the beginning, most of the physicians read out of curved reformats and all the fancy tools. But, as they get very experienced, when they see a normal case, they read from an axial. They might do what we call a 2D review, where they get more of a curved reformat or a multiplanar view. Then they will stop. When you have a difficult case, that's when all the tools become valuable. The fear that we didn't talk about is the fear of how long it takes to read these studies.

In the beginning, it will take a new physician a while to read a case. But once they are experienced, more of the doctors go back to the axials and then maybe a reformat image, if it is a pretty normal case.

FISHMAN: In the beginning of cardiac CT, which means like last year, everyone was trying to figure out if this is a 22% or is it 19%? People were twiddling around for hours arguing over 19% versus 22%. Now, of course, people are working with bigger numbers, such as whether or not it's <50%. That made life a lot easier. The other thing about the speed of reading is, of course, that after you have done enough cases, you realize that the easy cases are easy, and the hard cases are hard. But for those really hard cases, you could spend the rest of your life, and you aren't going to answer it anyway if they have that much calcification. If the study is in a very large patient, you could twiddle around forever and it is just not going to help.

WHITE: Yes, we have some of the same elements everybody is talking about now. Because we have a 3D lab and a 3D person, unless it's an urgent case (which is obviously the minority), we'll start with the curved planars because we already have them. They are

kind of our road map. If they look very clean, we know it is going to be a quick case. But then we always look at the axials and our vendor has a tool that is similar to what you described. We can put a point down if we have a question, and we can swivel around that point. Therefore, we can look at a fairly long segment of vessel in any plane we want. We can look at longitudinal or in the so-called IVUS view, straight on. That allows us to try to make more precise determinations.

But having said that, I agree with Elliot that we do not quantify things with 31% or 51%, we tend to give them ranges. The ranges we use tend to be 0 to 30%, which means yes, there's something there, but we're not in the least bit worried about it. Then at 30% to 50%, we are a little more worried about it. For 50% to 70%, there's something really there, but it's not necessarily subocclusive or occlusive. Finally, 70% and up; we don't really make a distinction if it is 85% or 99%. I don't think you can, honestly. So that is how we do it.

EARLS: Part of the answer, though, is that we're also not necessarily the end user. If a cardiologist or an internist is ordering the study, I feel obligated to show him what I'm seeing, which is why we do the curved planar images to the extent that we do. A lot of cardiologists, who I think are actually the end user taking care of the patient clinically, could just look at the axial images. You know it's normal, and they can stop looking. But I don't feel I could do that from a clinical marketing capability, because I have to prove to them what we see. So that obligates us as radiologists to do more processing on some of the other patients.

ZALIS: Given the sophistication of the available software and the large volume of data that we're presented with, what in your mind keeps you primarily attached to the axial image as your source of diagnosis?

EARLS: Actually, I was going to bring it up earlier, when Elliot was talking about the coronals. I just think "axially," since I've been looking at axial CT images for 15 years. I am just more comfortable looking at axial CT images.

WHITE: I agree with that. I think we're imprinted from the time we were residents and thereafter. To this day, I don't know if anybody else here does it differently. Unless there's a paradigm shift in the way radiologists are trained, I think it will stay this way. By and large, our residents are still reading primarily off the axials. Yes, they look at the other things and they can do the other things. I personally am concerned, it's isotropic data when we are looking at other things. But is it really quite as pure as the axials? You just have that suspicion.

FISHMAN: That is a neuroradiologist's point of view. It's isotropic here, but I still need another plane.

WHITE: That's a common perception people have.

FISHMAN: The way we do it is pretty much similar. I do look at the axials first because when you look at them, they also tell you if you have the right study and if you have the right fit. So there's a level of quality assurance, right? You may need to scream and holler. But you look at it, and then you also take a deep breath. If it looks really good on the axials, you know it's a slam dunk. I do look at the 3D, and, like the images I showed, I like to get a very good feel of the vascular mapping, looking for anomalies and the cardiac chambers.

As Jay said, you are also in business-building mode, and you need those images out there. Those axial images are horrible for business. Even though they are perfectly correct, nobody wants to see those. But I do look at the 3D images because I am very comfortable looking at 3D. But I think you can do a really good job on the volume-rendered images, even though people say you can't.

The third thing I do is the curved planar reconstructions. I admit that I really feel good about those curved planars. In a reasonably decent study, I think you get a very good feel about how the vessel really looks. Then you put them all together. I think you send the referring physician the curved planars and the 3D images. That is what really makes them enjoy the images and get a very good feel for it. But I think there are many ways to skin a cat. People just need to have one way of doing it, whatever that way is, in some logical fashion. I think that is where the fear really is in terms of doing things. Then, when you say 99% accuracy, it's just illogical.

WHITE: I think there are really a couple points about the studies. One is that they are almost exclusively single-center studies. There has been very little multicenter work on this. To my knowledge, there are almost no published studies on 64-slice CT because it takes so long to do a multicenter trial.

HAAS: There are two that are coming out: 464 and BCTO-2 just finished enrollment.

WHITE: But none have been published at this point. It's obviously good to have more of this data. So much of the data, whether it is stents or bypass grafts, or just native CTA versus cath, is from single-center trials. That is always going to raise doubts, I think.

EARLS: Every time I talk to a medical director of an insurance company, they remind me of that lack of data.

WHITE: Another issue is that catheterization is used as the standard of reference in most of these studies. Although cath is a wonderful study, to some degree it's comparing apples and oranges. You see different things on cath; in some cases, you see them certainly better. But it's not necessarily comparing like versus like.

EARLS: But for someone just starting out, it's easy to get discouraged when 3 of your first 4 cases go to cath and the cath results disagree with you. When I bring on more of my partners to read these, and that happens to them, they really get discouraged.

WHITE: But, in fact, the CTA may be right.

EARLS: Yes, but nobody assumes it's right.

FISHMAN: When you look at cases with extensive calcification and incredible disease, the cath can be read as normal. How could the cath be normal at a score of 2000?

ZALIS: I had a question about some of the more advanced views that you

are describing about the curved replanars. In the colon, a lot of advanced visualization technique is being brought to market, including filet views through which you unfold the colon, and ideas to reduce some of the ergonomic stress of reading the large volume of data. But those techniques invariably introduce anatomic distortion, sometimes to the degree to which it makes it hard to find the lesion you're looking for. Do you find even with isotropic imaging that you are seeing the same things with the curvy formats and other things?

EARLS: You do get some distortions, but I think it's easy to get accustomed to it. A lot of times the vessel will actually duplicate itself over a short segment, if it has an acute turn. You just realize that's what it is, especially as you look at it dynamically. It's really important to look at it dynamically and not at a static image, because that can be confusing, and you could make a misdiagnosis. We have a 3D lab too, and they process all of the coronary CTAs. The physician then sits down at the workstation and interacts with the study. When you see the images moving, I think you conceptualize it much easier in your brain than if you see a single static image.

WHITE: You also have to be a little careful with some of the reconstructions. This may depend on the vendor, but if you do curved planar reconstructions and the center line isn't in the right spot (which can happen either automatedly or manually), you can be fooled into thinking there's a stenosis when there isn't. So that is another reason to really check a couple different ways as to whether you really have something or not. That could be axial or volumetric or whatever.

FISHMAN: I think maybe we'll end on that point. But that is clearly the issue. You have all these tools, and it's like looking at an ankle fracture—if something is really there, it has to be there in more than 1 view.

Triple rule-out CT in the emergency department

At least half of the patients who come to the emergency department with chest pain do not have cardiac disease. Both triple rule-out and dedicated cardiac CT examinations have an important future in triaging such patients rapidly.

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Approximately 5 million people come to the emergency department (ED) with chest pain each year.[1] It can be very challenging to distinguish those with acute coronary syndrome (ACS)—a life-threatening condition that comprises transmural myocardial infarction (MI), subendocardial MI, and unstable angina—from those with other causes of chest pain, such as stable angina, pulmonary embolism (PE), and aortic dissection.

The potential role of triple rule-out cardiac computed tomography (CT) in the ED is a subject of intense interest. This article will review the clinical evaluation of chest pain in the ED, the options for using imaging to clarify the diagnosis, and the potential role of CT in improving the accuracy and efficiency of triage (Figure 1).

Acute coronary syndrome

Traditionally, ACS has been diagnosed on the basis of the clinical history, electrocardiogram (ECG), and cardiac enzymes. Often, however, the diagnosis is not clear-cut, and the ED work-up for chest pain can take ≥12 hours. Because ED physicians are extremely cautious in their approach to chest pain, approximately 50% of patients are admitted to the hospital for observation, many of whom have normal cardiac biomarkers and a normal ECG. Only 15% of patients actually have ACS. On the other hand, 2% to 5% of patients are misdiagnosed and inappropriately discharged from the ED, despite actually experiencing ACS or an MI.[2]

This dilemma highlights the need for improvement in the diagnosis of chest pain. Specific goals include a faster work-up and improved diagnostic accuracy. Imaging can play an important role in achieving both of these goals.

In determining the appropriate role for noninvasive imaging, it is useful to divide patients who come to the ED with chest pain into 3 groups. The first group is made up of those who clearly have ACS. The ECG is abnormal, the cardiac biomarkers are elevated, and the clinical history suggests a high risk for coronary artery disease. This group of patients is typically sent directly to the cardiac catheterization laboratory.

The second group is composed of those who have minimal risk for coronary artery disease and a reasonable explanation for the chest pain—those with musculoskeletal injury, for example. Such patients can be discharged home without further work-up.

The third group of patients, which typically comprises half of those who come to the ED with chest pain, is made up of those who have equivocal findings on the chest pain work-up. The history may be atypical, the ECG nonspecific or normal, and the cardiac biomarkers may be normal, at least initially. In this large group of patients, noninvasive imaging may be useful for clarifying the diagnosis.

Imaging options

Standard options include radionuclide myocardial perfusion imaging and echocardiography. Magnetic resonance imaging (MRI) has a potential role in the noninvasive triage of ED patients, as does multidetector cardiac CT.

Myocardial perfusion imaging with technetium-99m sestamibi has an established role in the evaluation of chest pain patients in the ED, largely because of its high negative predictive value (99%) for ACS.[3] Therefore, a patient whose study is normal has a very low likelihood of ACS. In addition, the sensitivity of this study for the early diagnosis of MI is approximately 92%.[4]

One disadvantage of radionuclide imaging is the need to move the patient out of the monitored environment of the ED in order to perform the study. Also, in most medical centers, nuclear cardiology services are available only during normal business hours. Finally, although a negative radionuclide study can rule out ACS, it provides no information on other possible causes of chest pain.

Echocardiography offers an alternative for the noninvasive evaluation of patients with chest pain. Among its advantages, echocardiography can be performed more quickly than radionuclide imaging, and it can be performed in the ED. In other ways, echocardiography is less optimal than myocardial perfusion imaging, however. Echocardiography relies on the assessment of wall motion

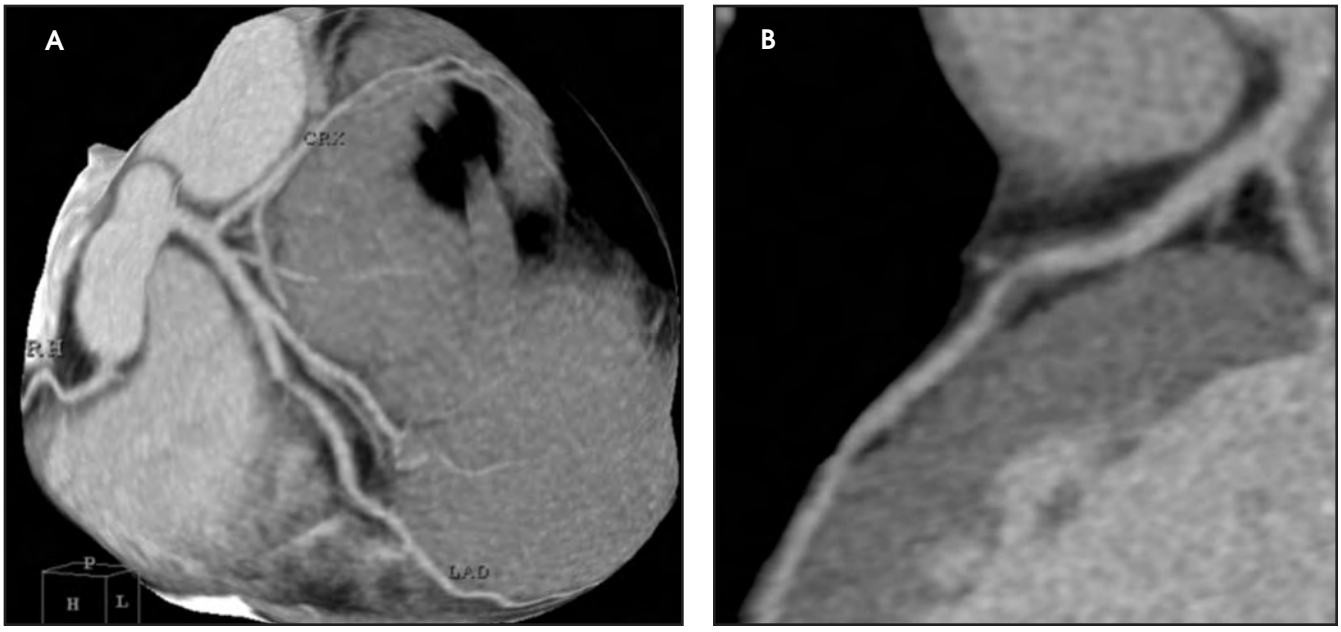

FIGURE 1. *A 49-year-old man with a coronary calcium score of 0. (A and B) Coronary CT angiography reveals a tight stenosis of the left anterior descending coronary artery, which was later confirmed on cardiac catheterization (not shown).*

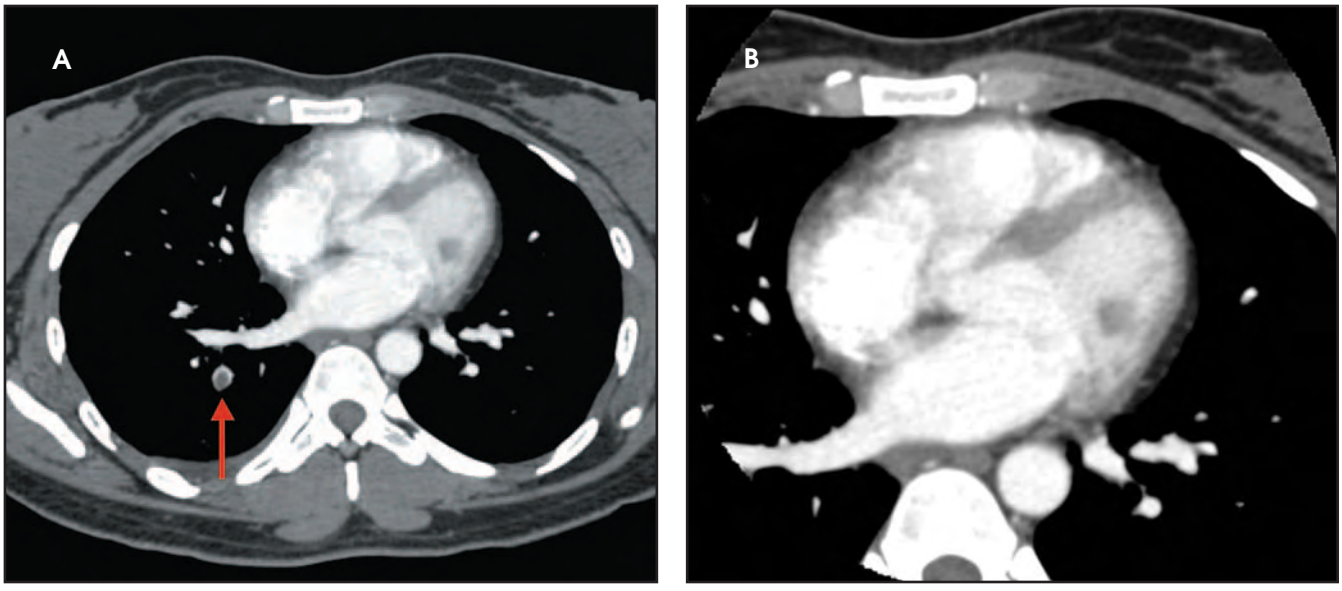

FIGURE 2. *(A) A pulmonary embolism (arrow) that is visible on a full field-of-view (FOV) CT study would be missed on (B) a dedicated cardiac study, given its restricted FOV.*

abnormalities to detect myocardial ischemia and infarction. Although its sensitivity for ACS is good (90%), its specificity is comparatively poor (53% for MI, 78% for ischemia).[5] Additional disadvantages include the inability to determine the cause of chest pain in patients whose symptoms have resolved, the difficulty in distinguishing acute and chronic wall motion abnormalities in patients with pre-existing coronary disease, and its limited ability to detect noncardiac causes of chest pain.

MRI offers a versatile option for the noninvasive evaluation of patients with chest pain, with its ability to evaluate myocardial perfusion, function, and viability. In a study of 161 patients who had chest pain but a nondiagnostic ECG, Kwong et al[6] found that contrast-enhanced, resting cardiac MRI had a sensitivity of 84% and a specificity of 85% for the diagnosis of ACS. There are, however, many disadvantages to using MRI in the evaluation of patients with chest pain. Among them are the need to transport patients out of the ED, long examination times, and the incompatibility of MRI with pacemakers, implantable cardioverter-defibrillators, and other metallic devices.

There are several reasons CT is gaining a foothold in the triage of patients

Table 1. University of Maryland scan acquisition and contrast administration protocols

Parameter	Coronary CTA only	Triple rule-out
kV	120	120
mAs	500	600
Field of view	250	400/250
Collimation (mm)	0.625	0.625
Reconstruction (mm)	0.675	0.9/.675
Direction	Cranial-caudal	Caudal-cranial
Time (sec)	8	15
Contrast administration		
Test injection (saline)	20 mL @ 6 mL/sec	20 mL @ 6 mL/sec
Injection protocol (Omnipaque, 350 mgI/mL; GE Healthcare)	80 mL (100%) @ 6 mL/sec 40 mL (50/50) @ 5 mL/sec 50 mL (saline) @ 5 mL/sec Bolus tracking	80 mL (100%) @ 5 mL/sec 50 mL (100%) @ 2 mL/sec 50 mL (saline) @ 2 mL/sec Bolus tracking

with chest pain. Scanner technology is improving rapidly, with better spatial resolution, better temporal resolution, and improved ECG gating. What may be less appreciated is the extent to which medical centers are increasingly siting CT scanners close to the ED. Although the driving force behind that decision are the many noncardiac indications for CT, including suspected PE, aortic dissection, trauma, headache, and abdominal pain, the proximity of the scanner to the ED makes cardiac CT a practical triage tool for the evaluation of patients with chest pain.

CT in the ED

There are two approaches to the use of CT to evaluate chest pain in the ED. The first is a dedicated cardiac study, such as one performed in an outpatient setting. The other option is a triple rule-out study, which is designed to simultaneously evaluate 3 potential causes of chest pain: coronary artery disease, aortic dissection, and PE. In reality, such an examination goes much further than the name implies, enabling the detection of pneumonia, pneumothorax, and other conditions.

In 2005, my colleagues and I published the results of a pilot study evaluating the triple rule-out protocol.[7] The study involved 69 patients with chest pain who were at low-to-intermediate risk for ACS. In addition to a standard cardiac work-up consisting of a clinical history, ECG, and cardiac enzymes, patients underwent a triple rule-out CT study. The majority of the studies (75%) were negative, as might be expected in this population. Of the 13 positive studies, 10 identified cardiac abnormalities. Even using a 16-slice CT scanner, we found the sensitivity of the triple rule-out study to be 87%, the specificity 96%, the negative predictive value 96%, and the positive predictive value 87%.

Both dedicated cardiac CT angiography (CTA) and triple rule-out CT involve ECG gating throughout the study and retrospective reconstruction in 10 cardiac phases. The triple rule-out study makes use of a larger field of view, however, and enables a more global assessment of the chest.

There are several trade-offs associated with the triple rule-out examination. The use of a different focal spot may reduce spatial resolution in the coronary arteries. Because the CT examination involves the entire chest, the total radiation dose is increased by ≥50%. In addition, it may be necessary to use a larger volume of contrast material, although this is not the case with our triple rule-out protocol.

On the other hand, it is easy to miss PE on a dedicated coronary CTA examination, because of the restricted field of view (Figure 2). To determine how frequently PE might be overlooked on a dedicated cardiac CT examination, our group conducted a study of 96 patients, 46 of whom had confirmed PE on chest CT.[8]

The scans were masked to mimic dedicated coronary CTA. Two readers who were blinded to the original findings reviewed the studies. They were able to diagnose only 37 (80%) of the 46 cases of PE. The remaining 20% were missed, in most cases because the pathology was outside the field of view. In a few cases, subtle evidence of PE was visible in retrospect within the cardiac field of view, but it would have been obvious had the readers had access to the full field of view.

Clinical protocol

At the University of Maryland, full-service CT evaluation of patients with chest pain is available from 7 AM to 5 PM on weekdays. Outside of those hours, night-staff residents or attending physicians (who are in the hospital 24 hours a day, 7 days a week), perform a preliminary reading. If the study is negative, as it is in approximately 50% of cases, the patient can be discharged home. If the study is equivocal or positive, the patient is held until the morning for formal image interpretation and, in some cases, stress testing.

The ED physician orders the scan as either a triple rule-out or a cardiac CT study. Patients with a heart rate exceeding 65 to 70 bpm are given 100 mg of oral metoprolol in the ED, at the discretion of the emergency physician. We nearly always must give patients intravenous beta blockers in the CT suite, as the heart rate is often >70 bpm. Our protocol calls for up to four 5-mg doses of metoprolol by intravenous injection.

Table 1 outlines our scan acquisition and contrast administration protocols for dedicated coronary CTA and triple

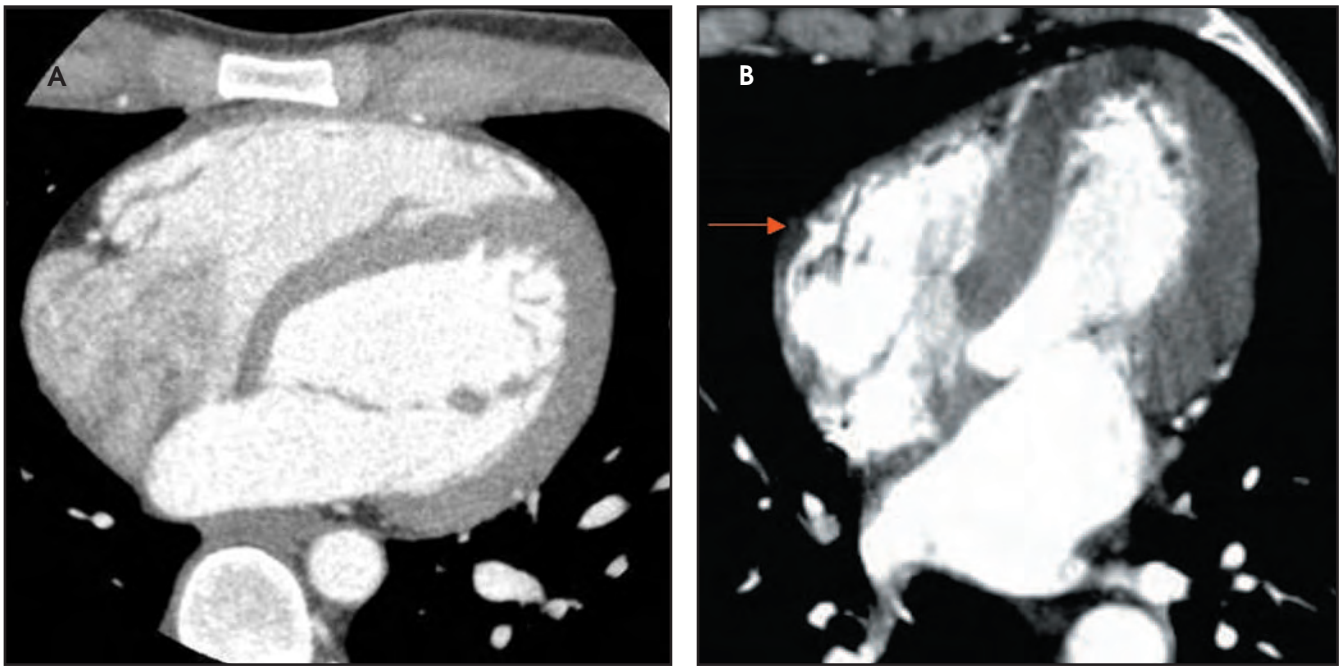

FIGURE 3. *(A) A dedicated coronary CT angiography protocol results in good opacification of the left heart, less intense opacification of the right heart, and good visualization of the right coronary artery. (B) With a triple rule-out study, the need to opacify both sides of the heart causes streak artifact (arrow) in the right coronary artery.*

rule-out studies. Note that dedicated coronary CTA makes use of a triple-phase injection. The first phase consists of 80 mL of pure contrast material (Omnipaque 350 mgI/mL, GE Healthcare, Princeton, NJ) injected at 6 mL/sec, followed by 40 mL of contrast material that is mixed half-and-half with saline and injected at 5 mL/sec, followed by a 50-mL saline chaser injected at 5 mL/sec.

The triple rule-out study involves a triple-phase injection, in this case consisting of 80 mL of pure contrast material injected at 5 mL/sec, followed by 50 mL of contrast material injected at 2 mL/sec, followed by a 50-mL saline chaser injected at 2 mL/sec. Dispensing with the injection of the contrast-saline mixture avoids diluting contrast material in the right heart. This improves opacification of the pulmonary arteries and enables an evaluation for PE.

There are trade-offs, however, as shown in Figure 3. The dedicated coronary CTA protocol results in good opacification of the left heart and less intense opacification of the right. As a result, the right coronary artery is very well visualized. With the triple rule-out study, the need to opacify both sides of the heart may cause streak artifact in the right coronary artery.

Also, because a triple rule-out study takes longer to perform than does a focused cardiac study (15 seconds versus 8 seconds), it is important that imaging of the heart take place during the first 8 seconds of the study, when opacification is optimal. For this reason, we reverse the usual order of the scan acquisition, starting from the bottom of the heart and scanning caudal-cranially.

After the scan is complete, a 3-dimensional (3D) technologist prepares advanced image reconstructions. The radiologist then does an independent review of the data set, including the axial images and curved planar reconstructions. We use an interactive tool to assess stenoses prior to issuing the report. On average, the time between the CT examination and the interpretation of the study by a radiologist is 1.6 hours.

Our standard reporting format for a triple rule-out study includes a description of the scanning technique, including any medications given to the patient to slow the heart rate or dilate the coronary arteries. Findings are reported for coronary calcium scoring and CTA, with detailed descriptions of plaque, stenoses, and other observations in each coronary artery. A functional assessment includes ejection fraction, cardiac chamber size, wall motion, or myocardial perfusion. Other cardiothoracic findings describe the aorta, pulmonary vasculature, lungs, and other chest tissue.

Strengths and challenges

CT brings many strengths to the evaluation of patients with chest pain. Since the introduction of the 64-slice scanner, dedicated coronary CTA studies have shown impressive results. Hoffmann et al[9] prospectively evaluated 103 low-to-intermediate–risk patients with chest pain, using 64-slice coronary CTA. A total of 14% of patients were diagnosed with ACS. Based on a 5-month follow-up, CTA was found to have a negative predictive value of 100%.

We have found a good correlation between coronary CTA and conventional invasive angiography in patients who have undergone both studies. Figure 4 shows a 58-year-old man who was found on 64-slice CT to have a lengthy stenosis of the left anterior descending arterty (LAD) that was composed of both soft

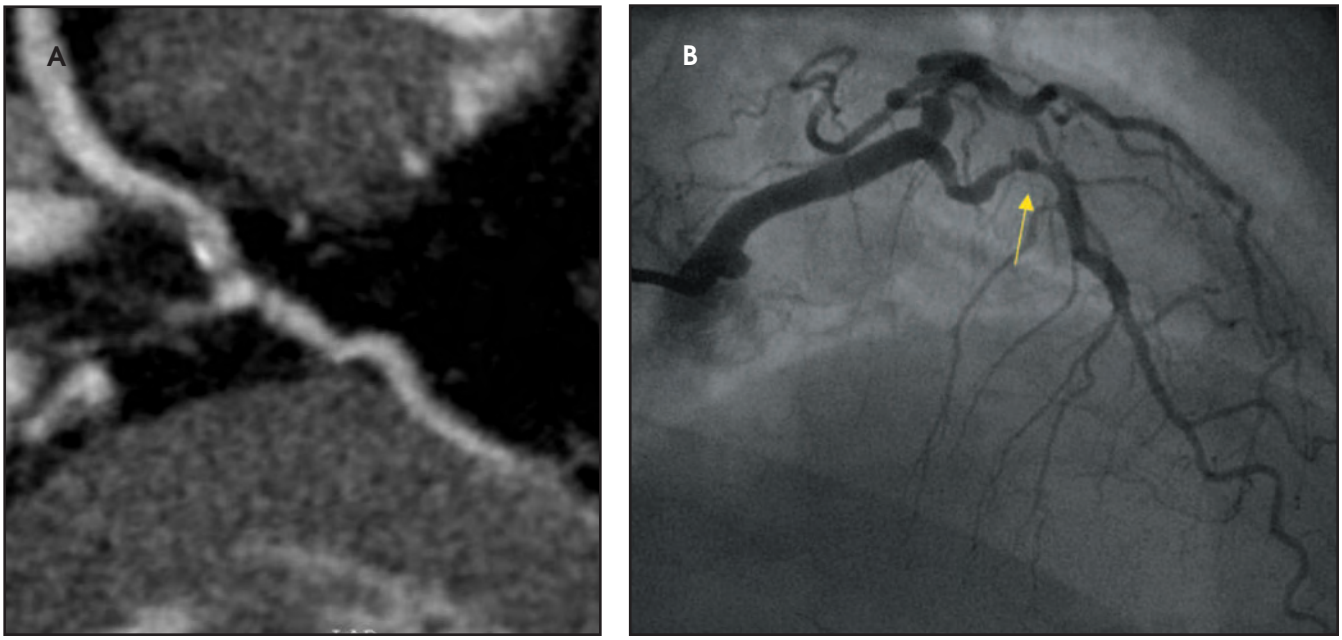

FIGURE 4. *Good correlation between (A) CT angiography and (B) cardiac catheterization in a 58-year-old man who was found on 64-slice CT to have a lengthy stenosis of the left anterior descending coronary artery (arrow in B), which was composed of both soft and calcified plaque.*

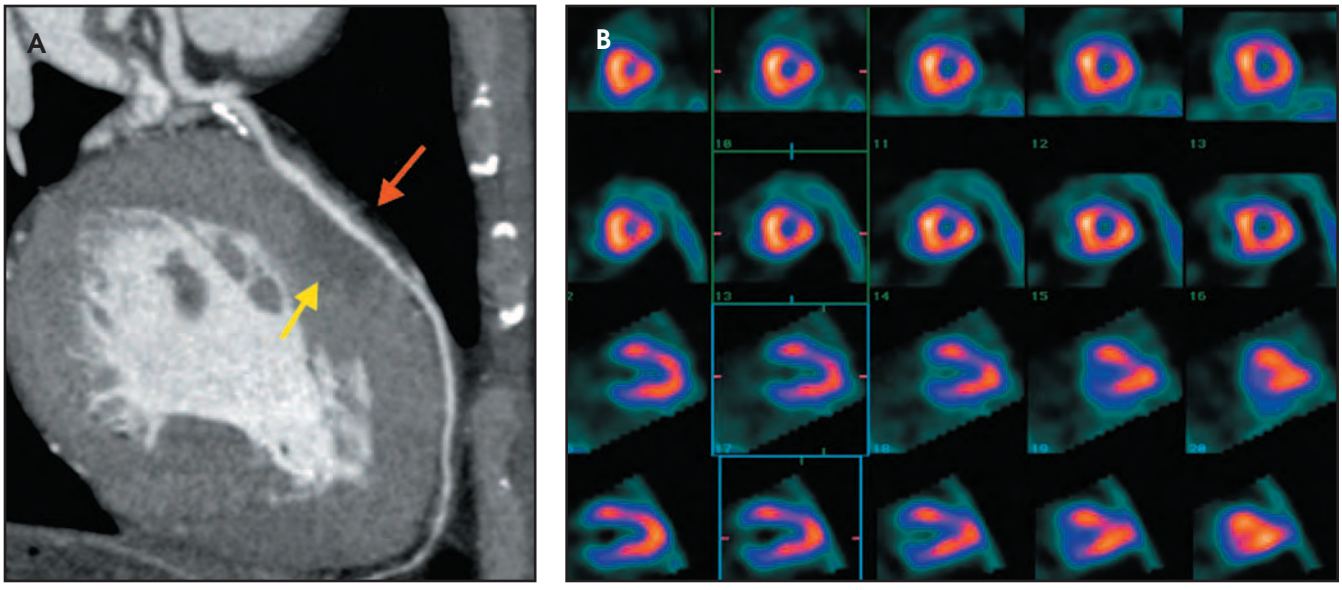

FIGURE 5. *(A) Coronary CT angiography (CTA) correlates well with (B) myocardial perfusion imaging in a 58-year-old woman who came to the emergency department with chest pain. (A) The CTA showed eccentric plaque that was causing mild luminal narrowing of the left anterior descending coronary artery (red arrow = myocardial bridge; yellow arrow = myocardial perfusion defect). The patient also had a sizeable myocardial bridge and an associated perfusion defect on CTA. (B) Myocardial perfusion imaging confirmed the presence of a perfusion defect in the anterior wall.*

and calcified plaque. These findings were confirmed on cardiac catheterization.

Coronary CTA also correlates well with myocardial perfusion imaging. Figure 5 shows a 58-year-old woman who came to the ED with chest pain. CT revealed eccentric plaque that was causing mild luminal narrowing of the LAD. However, this patient also had a sizeable myocardial bridge and an associated perfusion defect on CT. Myocardial perfusion imaging confirmed the presence of the perfusion defect in the anterior wall.

In some cases, coronary CTA and myocardial perfusion imaging are not concordant. In such cases, the clinician must decide which study is more reliable. It is increasingly clear that if the CT study is of good quality, its accuracy is quite high.

CT also faces several challenges in the evaluation of patients with chest pain. First, as a result of stress and pain, ED patients may not be as cooperative as

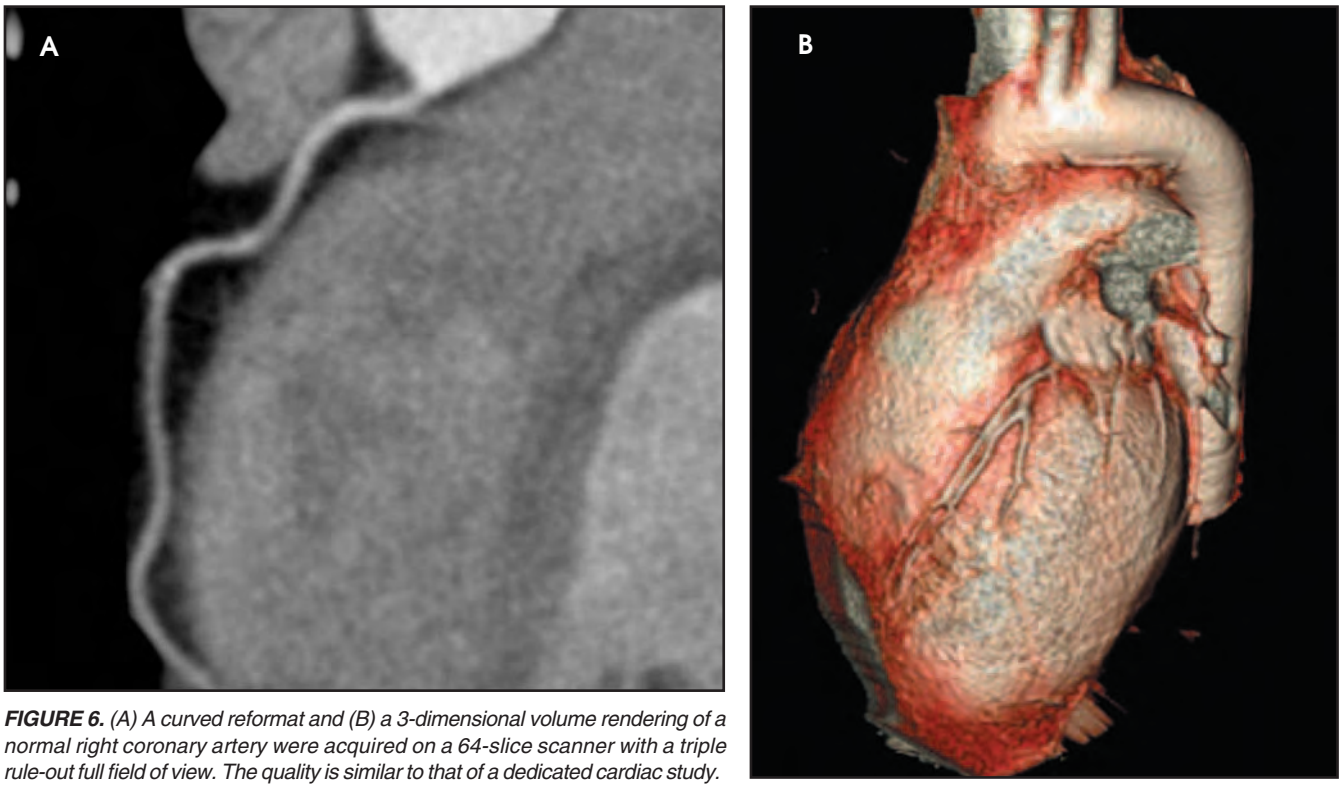

FIGURE 6. *(A) A curved reformat and (B) a 3-dimensional volume rendering of a normal right coronary artery were acquired on a 64-slice scanner with a triple rule-out full field of view. The quality is similar to that of a dedicated cardiac study.*

Table 2. Emergency department (ED) triage guidelines

Risk category	CT interpretation	Clinical guideline
Negative study	Normal scan	Discharge from ED; follow-up with personal physician.
Low	Coronary calcium score <100	Discharge from ED; follow-up with preventive cardiologist.
Intermediate	Coronary calcium score 100–400 Stenosis 30% to 70% in any vessel	Cardiology consultation in ED; discharge from ED or admission to hospital at cardiologist's discretion.
High	Coronary calcium score >400 Hard or soft plaque Stenosis >70% in any vessel Stenosis >50% in left main	Admission to hospital

outpatients. Often, however, this is not as large a problem as might be expected. By the time ED patients arrive in the CT suite, they have undergone the initial work-up, may have received pain medication, and have had ≥1 hour to regain their composure.

Radiation exposure is a concern. A gated cardiac CT scan exposes the patient to 8 to 15 mSV, although with ECG dose modulation, the radiation dose drops to approximately 5 mSv. A triple rule-out study delivers an effective radiation dose that is approximately 50% greater than that of gated cardiac CT. Still, it important to remember that CT may reduce total radiation exposure by eliminating the need for other examinations—for example, nuclear cardiology studies (8 to 30 mSv) or cardiac catheterization (3 to 15 mSv).

Technical and labor issues remain an ongoing challenge. Although 16-slice scanners sometimes produce reasonable images, a 64-slice CT scanner is necessary to consistently perform high-quality triple rule-out studies. Figure 6 shows a curved reformatted image and a 3D volume-rendered image acquired on a 64-slice scanner using a triple rule-out full field of view. The quality is similar to that of a dedicated cardiac study.

Even more difficult is the need to provide round-the-clock radiologist coverage in order to provide reports to the ED in a timely manner. Few institutions have completely solved this problem, but there are several options worth exploring. First, time-savings may be realized by assigning a 3D technologist to handle postprocessing. In some instances, 3D billing codes may generate enough revenue to support this position.

Second, in larger medical centers, residents and in-house staff physicians can be trained to do a preliminary reading of the CT studies during nonbusiness hours. Another option is to have an on-call radiologist read the study from a remote workstation or a portable device. It may also be worthwhile to contract

with a "nighthawk" radiology group to provide remote interpretations during nonbusiness hours.

Economic considerations present an ongoing challenge. In our 2005 pilot study of triple rule-out CT, we asked emergency physicians whether they would have otherwise ordered a CT scan to evaluate patients for noncardiac causes of chest pain. The answer was yes in only one third of the cases, suggesting that triple rule-out CT has the potential to spur overutilization of healthcare resources.[7]

The cost of each cardiac or triple rule-out CT study is $500 to $600, based on Medicare reimbursement rates. However, if CT eliminates the need for a rest/stress sestamibi scan, it saves $500 to $700. Similarly, eliminating the need for cardiac catheterization will save $2000 or more.

The greatest savings will come from avoiding unnecessary hospitalizations. In the same 2005 pilot study, we concluded that hospital admissions could be reduced by 20% to 30% if information from the CT scan is quickly made available to emergency physicians.[7]

A recent single-center study by Goldstein et al[10] further underscores the potential economic advantages of using coronary CTA in the ED. This study compared a standard diagnostic evaluation alone with a standard evaluation augmented by multidetector CTA in 197 patients with chest pain. Multidetector CT immediately excluded coronary disease as the source of chest pain in 67% of patients and identified severe disease in 8%. The remaining 25% of patients had lesions of intermediate severity or nondiagnostic scans, necessitating radionuclide stress testing. Researchers found that diagnostic time was reduced from an average of 15 hours to an average of 3.4 hours through the use of multidetector CTA. Average costs also dropped from $1872 to $1586. In addition, during follow-up, fewer patients who had been evaluated by CTA required a repeat evaluation for chest pain, when compared with those in the standard-care group.

A further challenge facing CT is the need to determine which patients with chest pain should have a CT examination and how to respond to its findings. Table 2 outlines guidelines for incorporating the results of CT into patient triage.

Since CT is most effective in those who are at low-to-intermediate risk for ACS, roughly 50% of patients have negative studies and can be immediately discharged from the ED. Another 20% to 25% have a near-normal CT examination, with a coronary calcium score <100. These patients have a low likelihood of ACS and can also be sent home, in this case with a referral to a preventive cardiologist. Therefore, approximately 70% to 75% of patients can be quickly triaged home using CT.

Patients with a coronary calcium score of 100 to 400 or a stenosis of 30% to 70% in any coronary artery are at medium risk for ACS and should have a consultation with a cardiologist before a decision is made about hospital admission or discharge. Approximately 10% to 15% of patients have a coronary calcium score >400, a stenosis >70% in any artery, or a stenosis >50% in the left main coronary artery. These patients are at high risk for ACS and must be admitted to the hospital.

During nonbusiness hours, we use a variation of this protocol, which we call dual-mode triage. Under this plan, 50% of patients with negative findings on CT are discharged from the ED, assuming that the resident or staff physician is confident in the findings of the preliminary reading. The remaining patients are observed overnight until a radiologist can do a final reading in the morning.

Conclusion

Many innovations are on the horizon for CT. These include faster gantry rotation (200 msec) for better temporal resolution, a larger number of detectors (128 to 256) for better longitudinal coverage, and thinner collimation for better spatial resolution. Another potentially important innovation is prospectively gated axial CT. This step-and-shoot technique enables a marked reduction in the radiation dose to <3 mSv in most patients, and to <1 mSv is some small patients.

Thanks to advancing technology, MDCT has substantial potential to improve the triage of patients with chest pain in the ED. To further define its value, careful evaluation in larger, multicenter clinical trials will be necessary.

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Discussion

ELLIOT K. FISHMAN, MD: I think that was a terrific talk. One of the things the ER brings about in terms of cardiac CT is that it shows, if it's successful, how much of a challenge it is actually going to be. At Hopkins, we keep 7 to 10 patients over night every night for nuclear stress testing, which takes all of the next day. But 90% of studies are negative, and that's the number everybody gets. So realistically, the biggest impact in the ER

setting, as Charlie mentioned, will be the negative study. That's the simplest, because those will be roughly 90% of the cases. Even if it ends up being 50% of your cases, it still can triage a lot of people very quickly.

Cardiac CT is still a challenge for everybody. But I think the additional challenge, and I can only speak for Hopkins, is that when you do cardiac CT during the day, you have your best techs, your prime physicians, your own nursing staff, and your own space. In the ER setting, the equipment is the same but you have techs who aren't as well supervised because they work at night. Like all night staff, night techs tend to be a unique bunch of people, and they do survive much better without supervision.

Also, in our situation, we don't have physical space in the ER so we can't do our own beta blocking and we don't have our own nursing staff, so we have to rely on somebody else, and we have residents in-house. So basically everything is 180° from the way it is during the day. But you still need to give a basic binary answer—yes or no. I think that is going to be a challenge. Now, the reality is that it's going to happen. I know it's going to happen because at RSNA last year, there were companies offering nighthawk cardiology.

The nighthawks, Paul Berger and those guys, know best. When they offer it, it's a real thing. They don't offer things that are not going to be successful. Jay, what are you in terms of cardiac scanning?

JAMES P. EARLS, MD: We don't do it in the ED as of yet. We'll scan people who get admitted to the chest pain observation unit but only from 8 AM to 4 PM. We don't offer it at night. But we just started our hospital-based program recently. So I don't have any experience with it yet.

MICHAEL P. FEDERLE, MD: I have a very personal experience with this. Last Thursday, driving home from work, I got atypical chest pain that felt like angina to me. My wife drove me back to the hospital, and it was now about 7:45 PM. Then the big rigmarole began. I got the EKG, with equivocal T-wave changes, so we're not really sure here.

We drew the trophonins, but it had only been an hour since I had it. We don't really know what this means so we can't rely on those. The regular techs that I would trust were gone. We don't have a 64-slice scanner in our ER yet. The people I would trust to do my cardiac CT were nowhere to be found because they were all home. So what could I do? I don't have many risk factors other than being an old white male. But that's enough, with the symptoms, so we couldn't just send me home.

But it's enough that they want to admit me to the hospital, and we'll keep a close eye on me, and they'll do something in the morning. That something could be that they'll get a CT in the morning or do a stress test in the morning. Or maybe we'd better just go do the coronary angiogram, which is what I had. It was completely normal, and I went home later that day. My groin still hurt a week later, by the way. The medical bill was $25,000. So it is a very real problem.

There are enormous issues facing us, and Charlie touched on all of them. I remember 25 years ago when we started writing about CT of the acute abdomen and abdominal trauma. I had radiologists complaining to me that they were losing sleep over that. That's a relatively easy study to perform and interpret. You could read the appendicitis or acute trauma study from your bedroom, and that's the way a lot of guys do it. The scan gets done, it's interpretable, and it's negative or it's positive, then you go back to sleep. Cardiac CT is not going to be so easy to do, so it's a very big issue.

CHARLES WHITE, MD: There is a fear factor, if you want to call it that. Closer to 10 years ago, when we started doing pulmonary CTA for PE, there was all this concern about whether or not the residents could read them at night. People got on 24/7 attending shifts. Several places were doing that to try to cover these studies. As time has gone on, it's pretty much died down. It's become an accepted part of what we do. In fact we do many pulmonary CTAs at night and essentially without a wrinkle.

So the past doesn't necessarily predict the future. But certainly there are things we can look at to say that perhaps this too can be worked out.

FEDERLE: That is an excellent point, Charlie. I can remember when we first started doing the pulmonary embolism CT scans in the ER. We very carefully measured our discrepancy rates between the preliminary readings and so forth. When it was a more primitive scanner—a 4-slice scanner—and the interpretation was relatively new to residents, there was a disturbing discrepancy level. It reached the point at which a friend of mine who runs the ER said, "I'm not ready to rely on resident interpretation of a CT scan. I'm still going to have to do the nuclear study or demand an attending do the reading."

Now, with better technology and more experience on the part of the residents, the discrepancy rate is very low and that's a dead issue. But it's going to take another quantum leap in technology and in staff experience to get that immediate performance and interpretation of a triple rule-out CT—to the level that we have achieved with the rule-out pulmonary embolism.

FISHMAN: At 16-slice, I would guess that 60% of the time they are great studies and you can at least say yay or nay. Another 20% of the time they are so-so studies, and the remaining 20% of the time you probably would have read it differently each time if you read it 3 times in a row. Now with 64-slice, 95% of studies are clearly yes or no.

We do a lot of cardiac CT, and we have really good techs at Hopkins. If you get really robust cardiac CT, I think the biggest variability would be in techs, especially at night. We have roughly 23 body CT techs, and we only have 6 who do cardiac CT. The others are trained, but it takes a special person to do cardiac CT. So that's the issue at night. You have tremendous variability, even with the same machine.

I read the scans from 5 sites in Baltimore. They have the exact same machines and use the exact same protocols, but they get different results. If it's from a specific site, it's terrific. If it's from another, I know it's horrible without even looking. There's such variability in the

studies. With cardiac CT, if you have a bad scan, it's just a waste of time.

WHITE: But we hope that there will be less variability with improved hardware and software. The tech will go in and use your protocol. Even though there may be a little bit of variability, it should not be as wide as it is now. That's what we hope.

FISHMAN: That's what has to be done. From the manufacturer's perspective, whether it's processing or something else, cardiac CT needs to be as clear as a PE study. Right now, during the day, particularly on dual-source scanners, we don't use beta-blockers to avoid the whole rigmarole of monitoring and waiting an hour. The dual-source scanner—or whatever the equivalent is going to be from other vendors—is the ideal ER machine. It does not require beta-blockers, and the patients can come right in the room. It doesn't matter, whatever the heart rate is. Until you have those things, I think it's going to be a challenge.

As Jay alluded to, the challenge we face is that our ER docs say to me, "Elliot, what difference does it make to us if it is 3 in the morning or 3 in the afternoon? It doesn't make a difference." To them, there's no logic of doing it at 3 in the afternoon and not doing it at 3 in the morning. We are expanding our hours to do it and will do cardiac CT until 10:00 or 10:30 PM, because we have a certain shift with the skill set. Then until 6:00 AM, we will not do it. Is that a viable way of doing it? It's a start, I guess.

But with the data coming out as good as it is, we're going to be really hard-pressed to limit it. The data from William Beaumont shows the financial models, and they found that cardiac CT offers millions of dollars of savings in addition to better patient care. Patient care is very important to all of us. When administrators hear that you would save $5 million or $10 million more in a typical ER in a year if you had a radiologist read this study in a timely fashion, that is going to drive the decision. With hospital costs what they are, money talks.

EARLS: What are the economics of the ER? They aren't using DRGs, like inpatients; they are more like outpatients. Do they bill fee for service?

FISHMAN: It's more like outpatient. But with cardiac care units, most ERs are overwhelmed with people. So our ER sees people in the hallway. Roughly, you spend $100 an hour having someone stay overnight, doing nothing, just waiting for studies the next day. If we can discharge those patients, we can bring more patients in. So one is just the sheer turnover.

EARLS: So the ER administration has financial incentives to discharge or admit patients as quickly as possible?

FISHMAN: They make money in volume.

FEDERLE: Emergency departments are under tremendous pressure for turnaround. They are monitored aggressively based on patient time from arrival to disposition. So, this means they have to get patients out of the ER—either home or admitted to the hospital.

WHITE: There are also a lot of issues with ERs being so clogged that patients are diverted to other places. They are on yellow and red alerts. Clearly, if you could move patients more efficiently through the ER, it would be viewed by everybody as a less stressful situation.

EARLS: Charlie, how does reimbursement work for your patients in the ED?

WHITE: We don't get reimbursed.

EARLS: You can get precertified, right?

WHITE: No. I don't know how it works on the clinical side. Generally, since most of what we're doing are triple rule-outs, we're billing them actually as chest CTs. One of the advantages of the triple rule-out study right now versus a dedicated cardiac is that many payers aren't paying for the dedicated cardiac scan, but when you go back to a chest CT, you don't really have that problem. So that is how we're handling it. Now, that is a moving target, and it might not hold in the future.

FISHMAN: The precertification is usually based on state rulings. You can't require precertification on ER visits.

FEDERLE: Precertification is not an issue for us.

EARLS: They could still come back and say it's not medically necessary or that it's investigational.

FISHMAN: The one thing about a triple rule-out study that saves your soul is that it's a routine PE study, in a sense. Then, by the way, we've also got the cardiac CT.

EARLS: So it's a routine PE study that takes you 4 times as long to read.

FISHMAN: Right. Of course, the issue is reimbursement in a fair fashion. Frankly, I don't think you are ever going to see that. You will never see 2 times the typical study. I don't see that possibility.

WHITE: But that is the whole issue for all of cardiac imaging. We can read 10 chest CTs in the time we do 1 cardiac CT, potentially. This is especially true if they are just quick follow-up CTs. I hope that gap will narrow. But if your sole motivation is to make a lot of money, it's going to take awhile before we are able to get there. Maybe we will at some point, but not today.

EARLS: But as of now, during the day, can your ER docs order as many triple rule-outs or dedicated cardiac CTs as they want?

WHITE: What's interesting is that they are not actually ordering them that often. Some of it is just an issue of transitioning their protocols. This is so new that they are doing it in a "catch as catch can" kind of way, as opposed to a protocol-driven way. Once they update the protocols, then I think we'll see a more defined pathway as far as when a triple rule-out study that gets done versus a nuclear study. It's not totally worked out yet. That's one of the ongoing discussions we're having, as to when we should do one versus the other.

DEANN HAAS: The biggest fear of the customers I have spoken to who are not are doing cardiac CT routinely is that this will become like the head scan or the PE scan. Right now, they see patients coming in for rule-out PE at 3 months, 6 months, and 9 months. So they are getting 3 PE scans within a year. Will the same thing happen with a cardiac CT exam?

WHITE: It's certainly possible. It's very hard to predict, but I would say

there's one big advantage of the triple rule-out study. With a PE study, even if it's negative, the patient could throw a PE the next day, so the scan could go from negative to positive in 1 day. That really shouldn't happen with the coronary CTA or with a triple rule-out. But if it's negative and they keep coming back with chest pain syndrome, for at least some period of time—you need to define what that period will be (3 or 6 months)—you can simply say that it was a good quality study.

EARLS: That's like a negative conventional catheterization. A lot of cardiologists won't repeat a cath within 5 years of a negative conventional cath.

WHITE: So you need to define how long that time period will be. So that does set them apart from PE a little bit.

FISHMAN: Everyone has the same problem. We are doing a lot of PE studies in the same patients who are just about 35 years old. There has to be a rule. We're working with ER physicians to address this because they are equally concerned, if not more concerned than we are. You can't be doing these triple rule-outs twice a year.

Since you've had the experience, Charlie, what are the other issues people need to address if they want to have this cardiac program at their hospital and do the scans in the ER? What are the other pitfalls that you've come across?

WHITE: I think probably one of the most important things is to get all the players on board. There are three groups to include, depending on the particular setup with the radiologists. The triple rule-out is obviously something that we do very well. You have to get the ED physicians on board. In a lot of places, they can be very conservative, so this may be a revolution in their way of thinking. You have to have a thought leader among the ED physicians who will push it for you. We do have that, fortunately. Finally, your cardiology group has to be on board because they will be doing all of the consultations when a certain fraction of the studies are indeterminate. That's already happening with the existing situation, but now the input source is different.

Before, decisions were made when it was an indeterminate clinical history and stress tests or whatever. Now it will be an indeterminant CT, and it involves a paradigm shift in their thinking as well. So it's not just radiology, it's a whole group of people that have to get together. I would say that is probably the biggest issue.

FISHMAN: One other thing about the ER setting is that although cardiologists in many places want to compete with radiologists, I've not heard of anyone from cardiology who wants to compete after 5 PM.

WHITE: Absolutely true. It's probably like obstetrical ultrasound; they have a problem doing the work after 5.

FISHMAN: Jay, what would make you do it at night?

EARLS: I think we need some movement from the ED to come to us. Right now, they've been very quiet about it even though they know we're actively involved elsewhere. I think we are going to do it, and I think it will be the right thing to do. It makes sense, it is good for patient care, and it is going to save the hospital money. It may be that the hospital will be the one pushing to do it. Right now in my group, we have 8 cardiac CT readers. So we could come up with a coverage plan to cover it because we do have a guy in-house 24 hours.

I actually did a study a couple years ago where I took a bunch of catheterization-proven cases and normal studies, and we read them just as 2D images. Then we re-read them 3 weeks later using all the tools. Just paging through the axial images, our sensitivities were about the same, and there was lower specificity just looking at the axial images. The reason I did it was that I was trying to think what we were going to do at 2 AM. Assuming we didn't have someone at the hospital doing it (we have more of a general radiologist there), we had to do it from teleradiology. If I just looked at the axial images, could I actually tell 80% of the people that they could go home? At least based on that study, I think that is probably the case. Then the other 20% might have to wait untill the morning to have a more formal interpretation done.

FISHMAN: There's no doubt that you don't have to hit 100% percent of the patients. You can dismiss the "normal" normals.

WHITE: That's right.

FISHMAN: If you could clear 50%, it would be a very successful program. You can also triage the obvious abnormal patients who need to get something else and the ones who could wait until the morning. Or some vendors are offering systems with which you can remotely run the workstation. So you can do processing from home. As those things become more widely available, I think it's just a matter of time before you will be doing it routinely. It's just a matter of when. What do you guys do, Mike? You have real ER docs.

MICHAEL ZALIS, MD: We have 64-slice CT in the ER. I know the cardiac program is evolving rapidly, although I don't think that it's 24/7 now. Certainly during the day, I know they are doing them constantly, and one of our main daytime scanners is booked with just cardiac cases.

FISHMAN: Those are read in India at night, I think. I read that in *The New York Times*.

ZALIS: One of my colleagues was suggesting that.

WHITE: We actually have 24/7 in-house coverage now for trauma and ED coverage. But this highlights another one of the issues, which is that we have full attending coverage. But not everybody in that group is comfortable doing cardiac CT or triple rule-outs in the middle of the night. So you have issues from the coverage point, to the training point.

EARLS: The guy who is there all night is already full, and he can't do anymore. So we're actually looking at a second person now.

ZALIS: The issue of 24/7 subspecialty coverage is very important. It's not enough to just have staff all day and all night. We need to have somebody who can do each of these acute things in the middle of the night.

FISHMAN: You can't be interrupted every 5 seconds during a cardiac CT. You can't be reading that case, and have someone stick another film in front of you every 3 seconds. It just doesn't work.

CT colonography: Toward a computer-aided, noncathartic examination

CT colonography offers a screening tool for colorectal carcinoma that is more acceptable to patients than optical colonoscopy and, therefore, has the potential to markedly improve screening rates.

Michael E. Zalis, MD

Dr. Zalis is the Director of CT Colonography at Massachusetts General Hospital, Boston, MA.

Colorectal carcinoma is the second highest cause of cancer-related death in the United States. Approximately 50 million people in this country are at risk for colon cancer and are eligible for screening.[1] As a noninvasive imaging technique that avoids the need for both conscious sedation and intravenous administration of contrast material, computed tomography (CT) colonography offers many advantages as a screening tool. New techniques that obviate cathartic bowel cleansing promise to further improve patient acceptance.

This article will discuss 4 aspects of CT colonography: the role of CT colonography in screening; noncathartic CT colonography; the role of computer-aided detection (CAD) in CT colonography; and issues involved in the implementation of CT colonography.

Screening

Colorectal carcinoma arises from adenomatous polyps that accumulate sufficient genetic abnormalities. These genetic changes are often concentrated in a specific set of genes that are associated with colon cancer. Lesions that exhibit high-grade dysplasia, usually in association with predominantly villous histology and a size ≥1 cm, have been classified as advanced adenomas and are considered to be committed to a pathway of uncontrolled growth. If left in place, these advanced adenomas will turn into cancer. Therefore, the target of screening is not colon cancer itself but, instead, an advanced adenomatous polyp. Because there is a well-defined, benign, and slow-growing precursor lesion—the resection of which substantially decreases the subsequent likelihood of colon cancer—screening for colon cancer differs from screening for other forms of cancer, such as malignancies of the breast or lung.

The biology of colon cancer is very favorable for early detection. The vast majority of detected lesions are much smaller and less clinically significant than the advanced adenoma. Moreover, the estimated "dwell time" for polyps to transition from normal mucosa to a significant lesion is estimated to be approximately 5 to 10 years. This provides an ample opportunity for early detection and intervention.

Figure 1 shows coronal and volume-rendered views of a well-circumscribed soft tissue lesion arising from the lateral aspect of the ascending colon. This 1.2-cm tubular adenoma is the type of advanced lesion that CT colonography is designed to detect.

Procedure

CT colonography can be broken down into 3 broad steps. The first is patient preparation, which is essential for a high-quality diagnostic examination. Currently, CT colonography requires cathartic cleansing that involves the use of various purgatives that physically cleanse the bowel. It is unquestionably the most onerous aspect of colon cancer screening in any modality and dissuades many people from undergoing screening. Finding alternatives to cathartic cleansing is a major goal in efforts to improve adherence to recommended screening guidelines.

It is becoming increasingly common to include fecal tagging as part of patient preparation. Fecal tagging enables cathartic agents to be at least partially replaced with an agent that tags the bowel contents.

Gas insufflation of the colon is the final step in patient preparation. It is increasingly done by an automated carbon dioxide insufflator, which is computer- and pressure-controlled and well accepted by both the patient and the technical staff performing the examination.

It is important to note that neither conscious sedation nor administration of intravenous contrast material is necessary for screening CT colonography in asymptomatic patients. This means that in the majority of cases, patients do not need an intravenous line—another aspect of colon cancer screening that many patients find unpleasant.

The second step in CT colonography is the scan acquisition. While the colon is not a rapidly moving organ, its superior portions are often affected by respiratory excursion; therefore, to ensure adequate spatial and temporal resolution, CT colonography requires the use of a multidetector CT scanner. It is recommended that the scanner have an image acquisition time of ≤500 msec and isotropic or

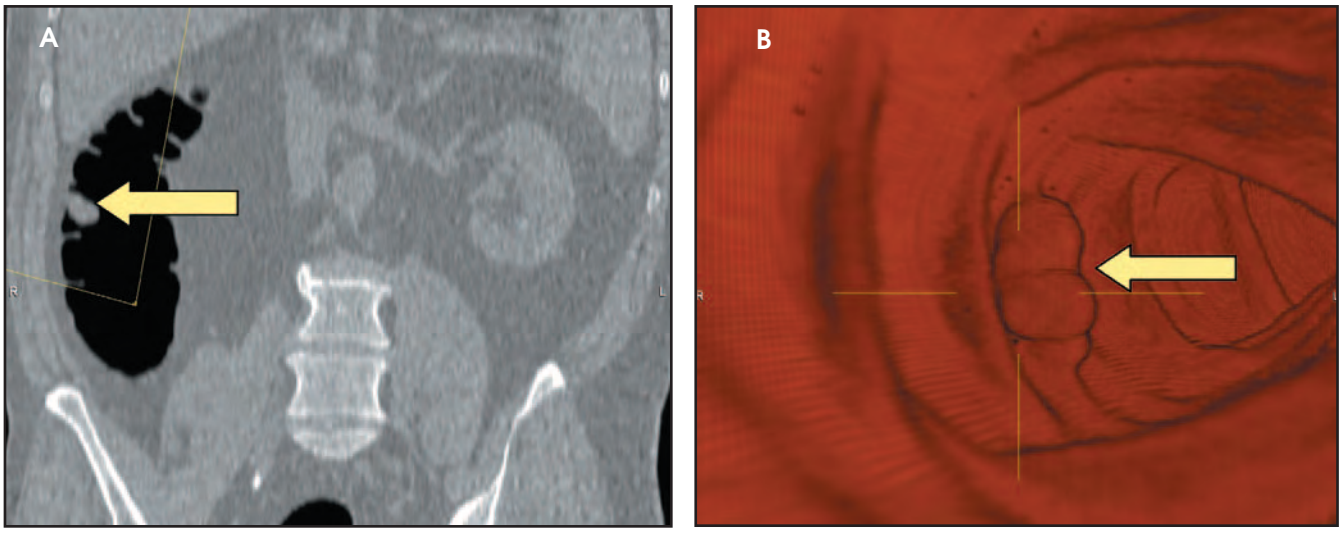

FIGURE 1. *(A) Coronal and (B) volume-rendered lumenal views of a well-circumscribed 1.2-cm tubular adenoma (arrows) arising from the lateral aspect of the ascending colon.*

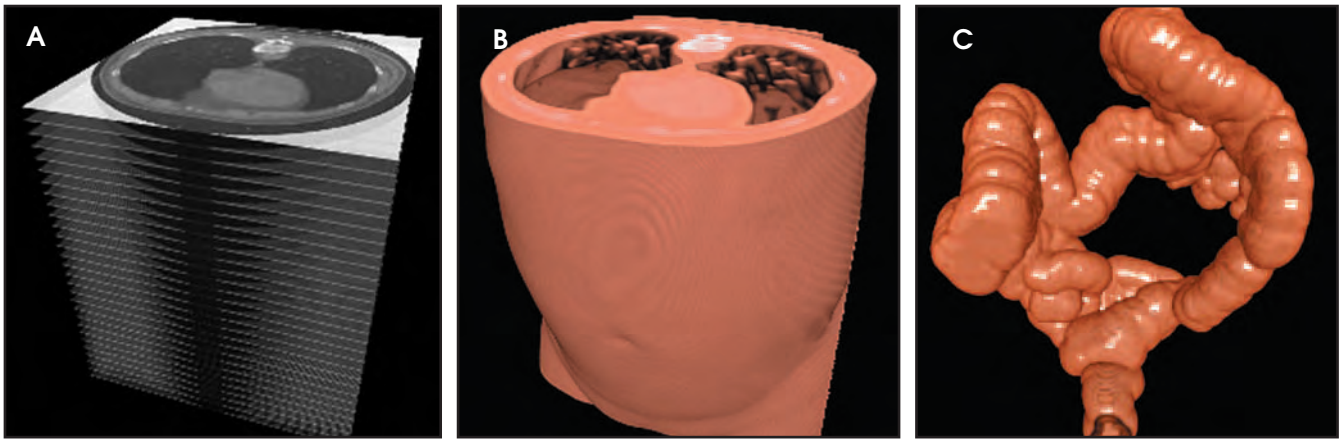

FIGURE 2. *(A) A CT colonography image acquisition starts with a stack of axial images that are (B) interpolated into a volume that is stored and evaluated on a computer. Various levels of image processing and computer-aided detection are applied to the volume. (C) It is then possible to segment just the colon from that volume, which then undergoes further processing and is evaluated by a radiologist for the presence of polyps. (Images courtesy of Hiro Yoshida, PhD, and Janne Nappi, PhD, Massachusetts General Hospital and Harvard Medical School, Boston, MA.)*

near-isotropic collimation of approximately ≤2.5 mm. There is very little evidence that a collimation of <2.5 mm offers a substantial performance advantage, however.

The scan encompasses the entire abdomen and pelvis and involves a breathhold of <20 seconds. It is a very-low-dose examination (typically <3 mSv) that is accomplished using 50 to 80 mA and 120 kVp. The radiation dose associated with CT colonography is approximately 20% less than that of a barium enema study.

It is important to understand how it is possible to perform such a low-dose study when scanning the entire abdomen and pelvis using a very large field of view. CT colonography is designed to detect a soft tissue polyp that typically is surrounded by gas. CT physics are such that fewer photons are needed to resolve this naturally high-contrast anatomy, enabling a reduction in radiation dose. In fact, because CT colonography is a screening examination that is performed in asymptomatic individuals, we are obligated to drive down the dose, and therefore the risk, as much as possible.

The third step in CT colonography is a 3-dimensional (3D) evaluation using either a dedicated workstation or dedicated software on a multipurpose workstation. The software should provide coordinated axial, sagittal, and coronal views of the entire abdomen and pelvis, coupled with excellent 3D volume-rendered views. Traditionally, 3D views have been used for problem solving, but a growing trend in CT colonography is the use of 3D views as the primary method for the detection of abnormalities. Novel display methods, such as those that mathematically fillet and flatten the colon, show promise; however, they can be associated with anatomic distortion. Their evaluation is in a relatively early stage, but they appear to increase the time efficiency of reading CT colonography studies.

Image acquisition and evaluation is illustrated in Figure 2. The acquisition starts with a stack of axial images that are interpolated into a volume that is stored and evaluated on a computer. Various levels of image processing and CAD are applied to the volume. It is then possible to segment from that volume just the colon, which undergoes further processing and is evaluated by a radiologist for the presence of polyps. The final result is a 3D fly-through of the bowel lumen. Color-mapping can be used on some systems to identify and classify lesions.

Several studies have shown that CT colonography is very well tolerated. In a survey of 100 patients, Svensson et al[2] found that 70% reported little or no discomfort with CT colonography, despite the absence of sedation. According to a study from the Mayo Clinic,[3] CT colonography is preferred by patients for colorectal carcinoma screening over both barium enema and optical colonoscopy.

Studies also show that CT colonography is very safe, with an extremely low morbidity and mortality. The largest series to show any complications associated with perforation reported a rate of just 0.04%. This study enrolled symptomatic patients and involved the use of a large catheter that is no longer in common use.[4] A separate review of approximately 6000 patients undergoing CT colonography for screening—and using more current techniques—failed to document any evidence of perforation.[5] By comparison, optical colonoscopy, the current standard for colon cancer screening, has a complication rate of approximately 0.4%.[6]

Noncathartic examination

Compliance with colon cancer screening guidelines in the United States is very low, far less than 50%, according to several recent surveys.[7-9] As mentioned before, the discomfort and embarrassment associated with standard cathartic bowel preparation is a major barrier to compliance.[10,11]

By offering the option of a "minimal prep" that includes fecal tagging and electronic cleansing, CT colonography has a unique opportunity to substantially improve colon cancer screening rates. Moreover, CT colonography will not necessarily draw patients away from optical colonoscopy. Instead, by creating an examination that is easier and more acceptable than optical colonoscopy, CT colonography is likely to recruit many patients who would not otherwise have participated in colon cancer screening.

Fecal tagging involves the use of oral contrast material to augment or replace standard cathartic bowel preparation. The ideal fecal tagging agent can be incorporated into the food the patient ingests with minimal impact on the diet. It renders stool distinct in cross-sectional appearance on CT and is not absorbed by polyps or folds. Therefore, a polyp continues to have the attenuation of soft tissue, whereas the attenuation of everything else in the bowel lumen is increased by the administration of the tagging agent. The use of fecal tagging agents in CT colonography has been associated with high sensitivity and specificity.[12,13]

Barium solutions taken 24 to 48 hours before CT colonography can be used as fecal tagging agents. Barium is safe, inexpensive, and inert. However, barium sulfate in its various preparations is insoluble and requires emulsifiers to remain in suspension. These emulsifiers are diluted during transit through the small bowel, resulting in relatively inhomogeneous fecal tagging in the colon. Furthermore, barium does not reliably or homogeneously tag enteric fluid. Hence, all barium-based tagging regimens also require the use of an iodinated agent to tag enteric fluid.

Iodine-based fecal tagging agents are either ionic or nonionic. They are delivered in a smaller volume than are barium-based agents. For example, an aliquot of approximately 7 mL with meals and snacks is sufficient with a nonionic agent, such as iohexol, as compared with 25 to 50 mL with many barium preparations. Iodine tags both fluid and solid stool and is translucent in the visible spectrum used for optical colonoscopy. Hence, it has very little, if, any impact on subsequent optical colonoscopy, which is a potential problem with barium tagging. However, iodine-based agents can cause diarrhea, particularly high-tonicity ionic agents.

Many investigators, including the high volume practice at the University of Wisconsin, successfully combine cathartic agents with both barium and ionic iodine for a reliable CT colonography preparation. In our own work at Massachusetts General Hospital, we have evaluated a large number of reduced-cathartic fecal tagging regimens.[14] Concerning reduced cathartic approaches to CT colonography, we found that a nonionic iodine-based agent, in combination with a minimal cathartic prepation, provided the best combination of patient acceptance and homogeneous tagging. The homogeneity of tagging, which is essential for electronic cleansing, is significantly better with iodine than with barium in our experience, especially for low- or noncathartic regimens.

We have recently instituted a truly noncathartic bowel preparation. This involves the ingestion of both a nonionic iodinated fecal tagging agent 48 hours before CT colonography and a commercially available zero-fiber meal in place of the regular diet 1 day before the CT study. The use of the zero-fiber meal kit in conjunction with tagging and postacquisition advanced electronic cleansing completely obviates the use of cathartic agents and appears to improve patient comfort. This approach now awaits validation in prospective clinical trials.

Electronic cleansing

Electronic cleansing involves the use of advanced image processing techniques to remove tagged colonic contents from the CT colonographic images. Essentially, it enables cleansing of the images after the examination, rather than physically cleansing the patient's bowel beforehand. Electronic cleansing of the bowel is challenging but has 2 key advantages. First, it preserves 3D visualization, which was established early on as an important visualization feature to maximize the performance of CT colonography.[12,15]

Early versions of electronic cleansing used a simple thresholding function. This resulted in a large number of artifacts—

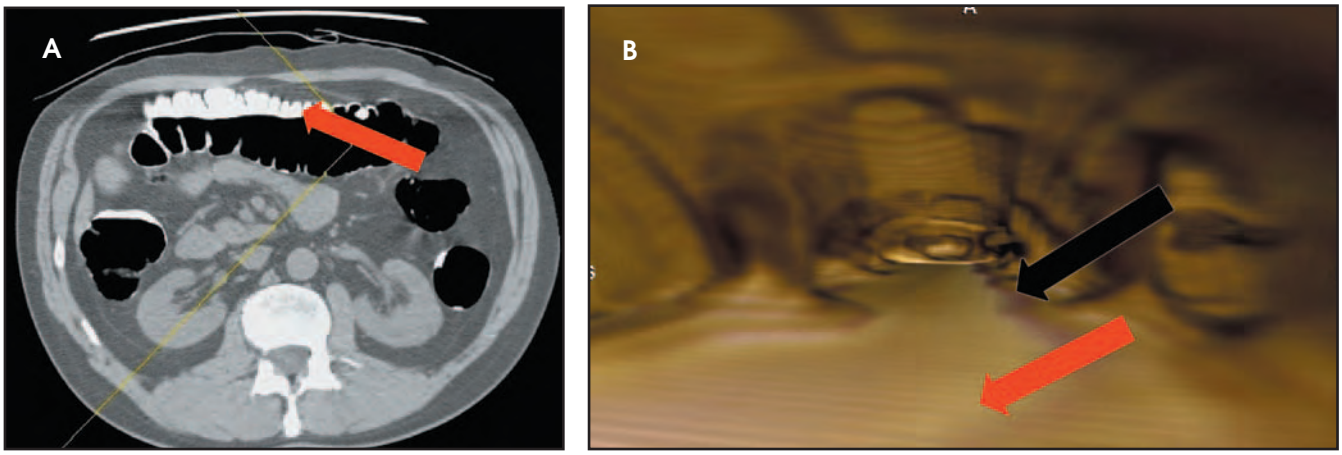

FIGURE 3. *(A and B) Early versions of electronic cleansing used a simple thresholding function. This resulted in a large number of artifacts—for example, bowel folds in the tagging area (arrow in A) that were subtracted from the image, a large amount of material left behind at the air-fluid meniscus (black arrow in B), and coarse mucosa (red arrow in B) underneath the area of subtraction as a consequence of imprecise electronic cleansing.*

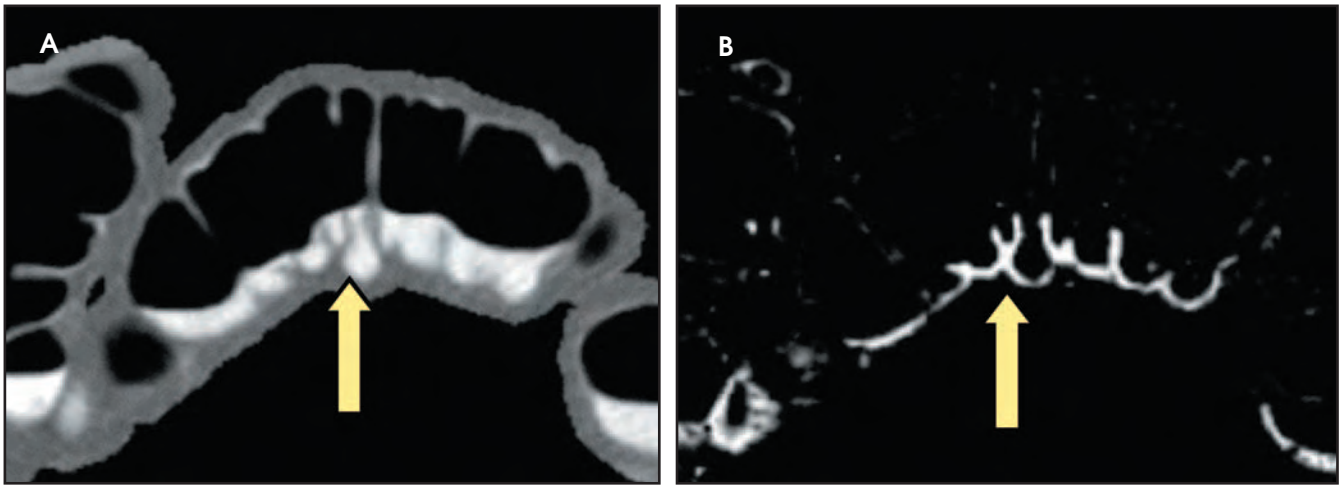

FIGURE 4. *Two coronal cutaway views. (A) A tagged colon segment before electronic cleansing (EC) and (B) the same image processed to specifically enhance folds, as identified by the particular morphologies of folds. The arrows indicate folds prior to EC that are well preserved following EC, based primarily on their morphology. (Images courtesy of Wenli Cai, PhD, and Hiro Yoshida, PhD, Massachusetts General Hospital and Harvard Medical School, Boston, MA.)*

for example, bowel folds in the tagging area that were subtracted from the image, a large amount of material left behind at the air-fluid meniscus, and "roughing up" of mucosa underneath the area of subtraction as a consequence of imprecise electronic cleansing (Figure 3). Today, a combination of sophisticated computer science and higher mathematics has improved the computer's ability to recognize structures in the CT colonography volumes.

Before electronic cleansing, it is common to see lakes of opacified contrast in the dependent portion of the colon. During fly-through, a large fraction of the anatomy is not visible to the reader, and, hence, a polyp could be missed underneath. After advanced electronic cleansing, the inferior dependent portions of the colon look as if they have been cathartically cleansed and, on fly-through, lesions are easily visualized.

Rapidly evolving work in electronic cleansing focuses on teaching the computer to read higher-level structures in the CT colonography volume, for example, using a Hessian matrix operator and an eigenvalue signature analysis. Work by Cai, Yoshida, and colleagues reveals that certain structures such as polyps and folds have characteristic morphologic signatures that distinguish how their shapes change in space (Wenli Cai, PhD, and Hiro Yoshida, PhD, Massachusetts General Hospital and Harvard Medical School, Boston, MA, unpublished data, May 2006). It is possible to selectively enhance structures based on their morphology and composition as a way of preserving important fold architecture. Figure 4 shows 2 coronal cutaway views —one of a tagged colon and the other of the same image processed to specifically enhance folds, as identified by the particular morphologies of folds. Other advanced approaches to electronic cleansing have been developed by Wang et al,[16] who have successfully applied expectation maximization algorithms to improve cleansing performance.

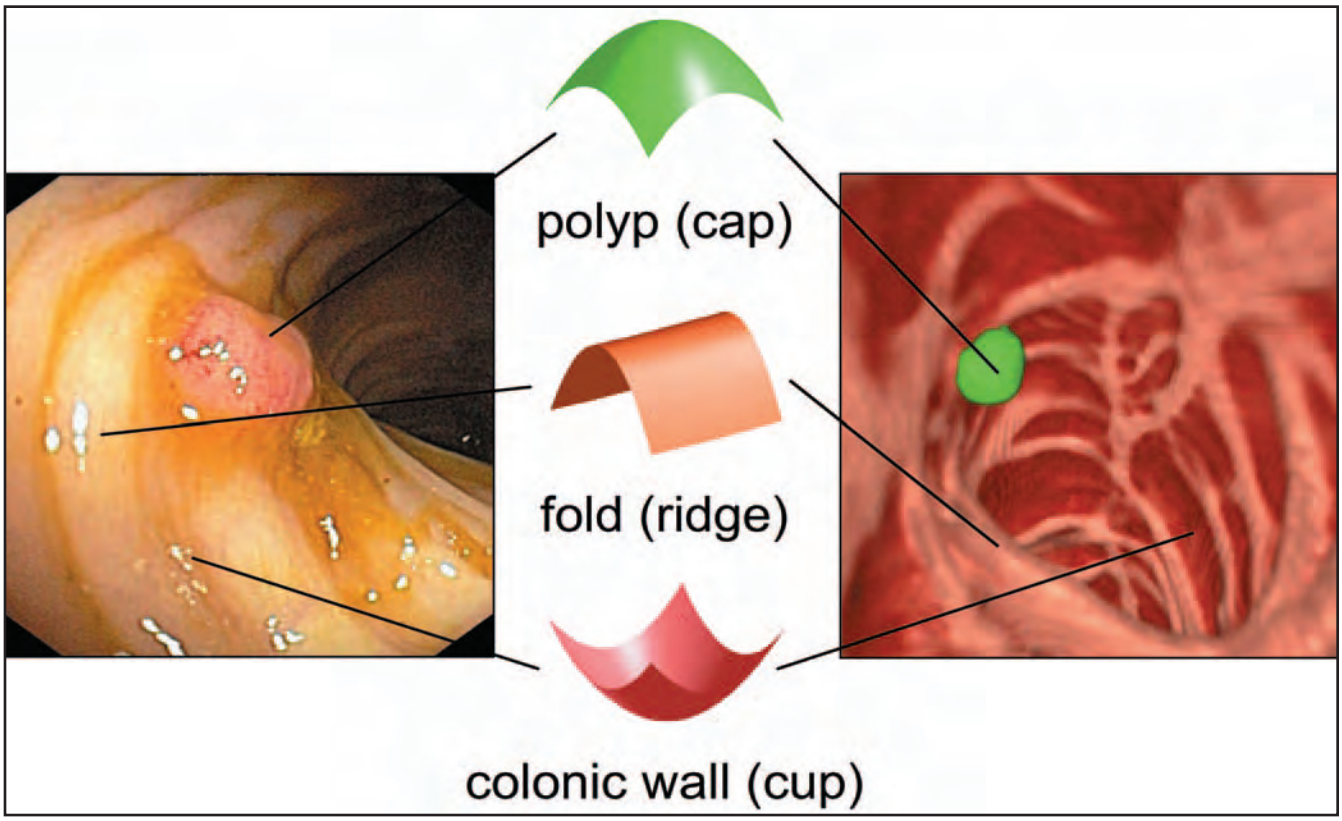

FIGURE 5. *With computer-aided detection, the computer analyzes various types of tissue seen on the image, characterizes them by their morphologies, and then color codes them. For example, tissue that is convex with respect to the colon lumen in 1 axis—tissue that has a ridgelike structure—might be coded in pink. Tissue that is convex with respect to the colon lumen in 2 axes—a structure with a polyp- or cap-like morphology—might be coded in green, and tissue that is concave with respect to the lumen might be coded in red. Using the computer to simply apply color-coding directly to the images automatically highlights a polyp in bright green. (Images courtesy of Hiro Yoshida, PhD, and Janne Nappi, PhD, Massachusetts General Hospital and Harvard Medical School, Boston, MA.)*

High sensitivity

With optimal technique, the sensitivity and specificity of CT colonography are both >90% for advanced adenomas.[12,13] In a recent large series, CT colonography was found to be statistically equivalent to optical colonoscopy.[12] Optimal technique entails the use of insufflation, fecal tagging, 3D visualization with high-quality software and hardware, and well-trained readers. Failure to adhere to these technical requirements results in a reduction in performance and suboptimal imaging.

In 2001, Callstrom et al[17] reported on the effectiveness of fecal tagging with 2% barium in an "enriched" (nonscreening) cohort of patients who did not undergo cathartic bowel preparation. In this small study, CT colonography had a sensitivity of 100% for the detection of polyps. However, it is important to keep in mind that the study involved patients with a prevalence of polyps higher than would be expected in a typical screening population.

Similarly, in 2004, Iannaccone et al[13] evaluated the use of iodine tagging without cathartic preparation or electronic cleansing in an enriched cohort of patients. CT colonography had a very high sensitivity (96%) for the detection of polyps, but approximately 15% of the study cohort experienced diarrhea.

An encouraging 20-subject pilot study from our own group showed that with electronic cleansing and a noncathartic or minimally cathartic regimen, CT colonography was able to detect adenomas ≥8 mm with a sensitivity of 88%. Readers rated 70% of cases as comparable to cathartic cleansed CT colonography in terms of image quality and readability.[18]

Recently, it has been possible to document another important point concerning electronic cleansing: The size of the polyps was preserved following electronic cleansing. Size is the single most important radiologic criterion for determining the risk that a polyp harbors dysplasia or carcinoma. Hence, it is critical that electronic processing does not artificially reduce the size of the lesions. Recently, in our own group, we observed that if the attenuation of tagging is kept to below approximately 800 HU, there is no pseudoenhancement and no statistically significant change in the size of polyps following electronic cleansing.[19]

Computer-aided detection

Computer-aided detection involves the use of mathematical analysis of the CT colonographic images to identify possible polyps. The computer acts as a co-reader to reduce either the time of interpretation, the rate of perceptual

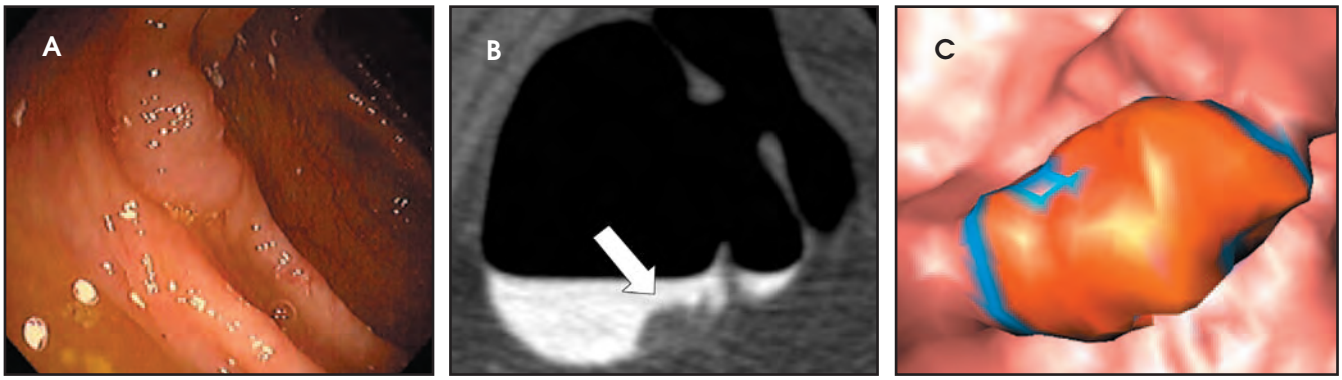

FIGURE 6. *(A) An endoscopic view of an 0.8-cm confirmed villous adenoma. (B) An axial image reveals a lesion (white arrow) submerged in tagging material. (C) A volume-rendered CT colonographic image of the lesion shows where artificial highlighting color has been automatically applied by the computer-aided detection algorithm. (Images courtesy of Ron Summers, MD, PhD, National Institutes of Health, Bethesda, MD.)*

errors, or inter-reader variability. Software for CAD has been implemented by several academic centers, including our institution, Stanford University, the National Institutes of Health (NIH), as well as several commercial vendors.

With CAD, the computer analyzes the attenuation, morphology, and texture of features imaged in a volume and then assigns these features into meaningful categories. Almost always, this categorization process is based on training and learning algorithms developed in the arena of artificial intelligence. Figure 5 illustrates this categorization. For example, tissue that is convex with respect to the colon lumen in one axis—tissue that has a ridge-like structure—might be coded in pink. Tissue that is convex with respect to the colon lumen in 2 axes—a structure with a polyp- or caplike morphology—might be colored in green, and tissue that is concave with respect to the lumen might be colored red. Using the computer to simply apply color-coding directly to the images automatically highlights a polyp in bright green.

To eliminate the large number of false positives that can occur with this technique, it is necessary to apply sophisticated machine learning techniques, such as Bayesian neural networks or support vector machine methods. According to a study by Yoshida et al,[20] use of such techniques with CT colonography CAD results in a sensitivity of 93% for the detection of lesions ≥8 mm and a reduction in the false-positive rate to approximately 3 per acquisition.

A report from Summers et al[21] at the NIH showed similar data: a very high sensitivity (89.3% for lesions ≥10 mm) and an acceptably low number of false positives per patient (mean 2.1). Figure 6 displays endoscopic and CT colonography images, showing how CAD software has automatically detected and highlighted an advanced adenoma for the reader to review.

Computer-aided detection software is rapidly becoming a commercially available standard option in CT colonography interpretation software. The technique is still in evolution, however, and prospective validation studies are currently limited. While CAD can be used with a noncathartic tagging and scanning regimen (as has been described here), it must be adapted for that purpose. In addition, prospective data defining the added benefit from CAD are still limited. The best reader paradigm for implementation of CAD also remains unclear. Should CAD be used to prescreen all images? Should the radiologist read concurrently with CAD? Should CAD act as a second reader after a human has made a full and complete evaluation? These are open questions that will be answered in upcoming clinical trials.

Prospective studies of CT colonography using noncathartic techniques along with the use of CAD software, are under way. A collaborative trial involving investigators at Massachusetts General Hospital, Partners HealthCare, and the University of California, San Francisco is evaluating polyp detection and subject acceptance with noncathartic CT colonography used with both electronic cleansing and CAD.

Future directions

Although advanced adenomas are the target of screening for colorectal cancer, the use of CT colonography as the screening tool raises questions about the potential role for surveillance of intermediate-sized polyps (6 to 9 mm, when <3 such lesions are present), rather than automatic referral for resection. This issue is unique to noninvasive imaging. With optical colonoscopy, there is minimal incremental cost to removing small polyps. Indeed, there is financial incentive to remove all lesions, regardless of their clinical significance, which for lesions < 6 mm is very low. When the screening tool is a noninvasive imaging test, the problem must be considered with greater clarity.

Lesions of <1 cm have ≤5% chance of being an advanced adenoma and a ≤1% likelihood of harboring frank malignancy. There are endoscopic data suggesting that many intermediate lesions regress spontaneously when followed serially by endoscopy.[22] Therefore, it is important to define what an "actionable" lesion is. Should it be defined as an intermediate-sized lesion that exhibits growth over a short period of time (1 to 3 years) or, perhaps, all lesions ≥1 cm? In the future, prospective studies of CT colonography will better define the growth rate of lesions and help to determine which lesions found on screening merit resection. Until such questions are answered,

the clinical approach to intermediate-sized lesions will be individualized, including the decision to follow-up by optical colonoscopy or conduct surveillance by CT colonography.

In projecting the future of CT colonography, it is important to consider whether it will be possible to meet the demand for this screening examination. Scanner capacity is not an issue in this country, as multidetector scanning is now widely available. The larger issue is a shortage of trained readers. There are approximately 35,000 radiologists in the United States; however, CT colonography is not yet a standard examination performed by most, nor is proficiency in reading CT colonography incorporated into board certification standards. It is expected that board certification standards will change in the next few years. Today, however, it is important to consider that CT colonography is highly amenable to teleradiology, using image compression and transmission to an expert center for interpretation.[23] The use of teleradiology could help to alleviate the short-term shortage of trained readers.

Reimbursement will play an important role in the future of CT colonography. The first round of local Medicare coverage is in place across the United States, and in most regions there is coverage for CT colonography when it is used as a "completion examination" in cases in which optical colonoscopy cannot reach the cecum (the terminus for a full colonic screening). Broader coverage of CT colonography by private third-party payers is mixed, although it will likely improve in the wake of the preliminary, positive report of the American College of Radiology Imaging Network (ACRIN) National Colonography trial[24] and the recent comparative experience at the University of Wisconsin.[25] Both of these studies appear to strongly support the utility of CT colonography in the screening setting, although full analysis and publication of at least the ACRIN data has not yet been completed. The important coverage decisions will also likely hinge on the independent assessment of CT colonography by the major medical societies, which should be forthcoming.

Conclusion

CT colonography is likely to have an increasing role in colon cancer screening. Augmentation of CT colonography by fecal tagging can be accomplished by using barium and iodine, and there is growing support for the use of iodinated agents alone. Electronic cleansing preserves 3D visualization when tagging is used but requires sophisticated software. Computer-aided diagnosis performs quite well, especially in terms of sensitivity, and will become a standard option for most interpretation platforms. Noncathartic CT colonography looks promising in pilot data, and the technique may help to reduce barriers to participation with recommended screening guidelines, potentially extending the benefit of screening to more at-risk individuals. Further data prospectively evaluating noncathartic technique is forthcoming. Recent strong evidence supporting cathartic-based CT colonography for screening will likely lead to improved third-party coverage.

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Discussion

ELLIOT K. FISHMAN, MD: It's very interesting that the talk on virtual colonoscopy and where it stands parallels the talk about cardiac CT in many ways. It has the same issue in that the capabilities are out there. Do GE customers

routinely have virtual colonoscopy software if they buy the workstation?

DEANN HAAS: Roughly 90% of our scanners go out with the cardiac software. We sold more than 200 packages of the virtual colon package in the United States and 400 in Europe, so it is growing a little faster overseas.

FISHMAN: But the same challenges occur. The first question I would ask is one of the things you notice for cardiac CT. From the American College of Radiology or the American College of Cardiology, there are well-defined training requirements, and both societies have different requirements for obvious reasons. Do you see anything similar for colonoscopy? If you're doing virtual colonoscopies, are there certain requirements or training hours?

MICHAEL E. ZALIS, MD: There are a lot of issues to talk about with this. It's already clear from the literature that training is essential. With untrained readers, performance is not as good. A number of published studies have shown that a minimum of 50 exams is required for people to really ramp up on their learning curve to be able to perform at an optimal level. But the best way to handle mandating training is complex. The most strict and severe approach would be a formal accreditation process, which would require a reader to pass an exam to be certified, and get an extra formal imprimatur from an organizing body. But that's very expensive to do, and there's some resistance to it in terms of how much added benefit it offers. Something like a registry is another option.

Certainly it would help to have a standardized protocol and syllabus during training, as often happens, for example, during mammography. In mammography training, in many cases you are required to go through a certain number of screening exams during residency training in order to reach a certain level of proficiency. So I think there will be a standard that's established. Certainly 50 or more cases is a reasonable minimum baseline to start. The exact form of that is still an open question.

FISHMAN: Another question is also similar to a question I asked about cardiac CT. What's the best way of reading a virtual colonoscopy? There are many different tools from CAD and the question even of just 2D versus 3D reading. This is one of the questions that will be addressed by the ACRIN study. What do you think the optimal reading in your practice is?

ZALIS: I'll try to separate what is data supported versus my own experience, because I've read thousands of these things now. The data isn't clear on this right now. There are very good studies that show that well-trained readers using otherwise optimal technique with 2D images can detect things very well, certainly in enriched cohorts of subjects. There has been some question about whether or not 2D primary technique performs as well in screening a low prevalence population, though the preliminary presentation of the ACRIN 6664 trial data seems to put that question to rest. There are also very good data that shows that 3D imaging with a primary 3D fly-through technique provides very, very good performance, both in an enriched and as well in a low prevalence screening-type cohort.

Personally, I have migrated from a primary 2D approach to a 3D approach. First, ergonomically, I find that it's easier, especially if there's an automated navigation system, which many of the packages now offer. With this, you are literally on a roller-coaster ride through the colon and navigating automatically. It's much easier to read an exam. I can read one of these, including the extra colonic soft tissues, in 10 minutes or less, when I'm up to speed and in a quiet place.

The second thing is that I find that my own sensitivity increases. I see things on the 3D view that I wouldn't typically see with the 2D. It's not black and white, you can miss things from the 3D perspective. Having 3D as a primary source doesn't allow you to ignore the 2D. My own personal reading paradigm is to start with the 3D—that's what I rely on for detection. I always double check with one pass through the 2D images to make sure I'm not missing something that a regional lumenal narrowing actually represents, ie, a subtle anular lesion.

FISHMAN: In your opinion, why is it so hard for people to get involved with virtual colonoscopy? The data published in *JAMA* was very, very positive and people's experiences are positive. Why do only 10% of people do it?

ZALIS: I think there are two things to be said about that. One is politics and the other is an accumulation of data, and an increasing bar required for the implementation of a new test. We're talking about doing something on a big scale to a lot of people. I think it's very reasonable for the government and other third-party payers to require a really solid amount of data to prove that doing this is going to improve patient health status and outcomes in the United States. Certainly, we have a good foundation in terms of the benefit of colon cancer screening. If we can reliably show equal efficacy in the detection of polyps—and I think effectively we're there now with virtual colonoscopy—you will start to see endorsements in data-driven imprimatur or statements from other parties confirming that this is a viable option.

Until now, there has been variability in part because the technique was not well enough standardized to get optimal performance in terms of collimation, reader training, and the use of tagging. Certainly, the CT technology has evolved rapidly, and it has made a big difference in our performance. Also, unlike in certain other countries, in the United States, there's more of an artificial antagonism between specialties in terms of one or another specialty feeling inappropriately threatened by the implementation of this technique, as if it will take business away from another group.

The University of Wisconsin is the only center that I know of with two programs running in parallel—that is, they have a CT colonography and an optical colonoscopy screening program running simultaneously on the same population of patients. They have recently published on their ability to detect the same number of advanced adenomas with approximately one fifth the number of optical colonoscopies. Significantly, the utilization of optical colonoscopy hasn't substantially diminished.

What has happened is that they have converted a lot of screening exams into therapeutic exams. One could make a pretty good argument that optical colonoscopy is an excellent therapeutic exam; with a good, inexpensive, safe, noninvasive screening exam, we could use it more and more as a therapeutic exam.

JAMES P. EARLS, MD: It's the same argument you can make for coronary CT and interventional angiography.

FISHMAN: The program was the Perry Pickhardt program, and it's not really parallel; they are actually working together a couple of days a week. They screen all of the patients in the morning, and they have empty slots for optical colonoscopy. Whoever has something suspicious on the virtual study then gets the classic colonoscopy. So for the patients, it's one prep, one time. So it may be the best model of specialties working together, where it is a win/win for each specialty, and it is also a win/win for the patients.

ZALIS: They've also doubled the number of patients they've been able to screen in that area, which is most important, I think. If we take a step away from marketing and reimbursement issues, the bottom line is that people should not be dying of colon cancer in this day and age. We simply need a better way to get people to participate with screening.

FISHMAN: Another thing they did cooperatively was that the payers recognized they wouldn't be paying twice as much money, so it was more logical. So they were able to get reasonable reimbursement for the virtual colonoscopy side, which most of us have not been able to do. Mike, what are you doing?

MICHAEL E. FEDERLE, MD: I think the drawbacks are that there's a big investment of time and some equipment. Perry Pickard has been able to have both excellent clinical results and reasonable reimbursement. But he invested thousands of hours in lobbying the payers. They have trained a lot of people in their practice to do it. I think what's holding it back is that you have to say to the average radiologist, "We want you to invest a lot of time to have several of your people get the 50 cases of training and really learn how to do this well. You need to buy a certain amount of equipment, increase your skills, and, by the way, you may not get paid for it." They are going to say, "See you later."

But I really think that we're right on it, and I think this year will be the tipping point. I really do. Up until this point, people have still been debating about technique: 2D versus 3D, cleansing or no cleansing, tagging or no tagging, etc. A lot of guys are going to say, "I'll wait on the sidelines a little bit." Some are waiting until the ACRIN trial results come out.

I've talked to a lot of our industry colleagues as well, and they agree that people will probably say, "You know the results are probably going to be positive." If everything was absolutely clear cut, and reimbursement was robust and immediate, we'd probably run into a big problem with the gastroenterologists. This may be the year when radiologists say, "We're going to bite the bullet, get trained, start offering it, and be proactive."

FISHMAN: It's interesting. I will just read you the statements from the American Gastrointestinal Association. This is from early 2007: "Guided by the principle that gastroenterologists should be able to use and manage any technology that can enable them to provide better patient care, the AGA Institute is taking a leadership role with CT colonography. With the best interests of patients in mind, we are taking steps to monitor the evolution of the technology, create standards for the performance of the tests, create a business model to guide members who want to bring the technology into their practices, and establish reimbursement codes for gastroenterologists."

ZALIS: I know the individual who wrote that particular piece and I'm not surprised. It's indicative of much of the attitude and resistance that we've met by this. Certainly there's a sense that the gastroenterology community have been the prime leaders in colon screening. They could rightly feel a certain ownership of that particular kind of screening.

I will go so far as to say that I think gastroenterologists could detect polyps very well on a virtual colonoscopy. However, all the other soft tissues of the abdomen and pelvis inextricably come along with the colon on this exam. So there has to be an appropriate mechanism, either someone fully trained to read both, or some other method whereby all the extra soft tissues are handled. Certainly, it's clear, although I didn't talk about this in great detail, that in 5% to 10% of cases, you see extracolonic soft tissue abnormalities that need some kind of follow-up. Approximately 5% to 10% of those are really clinically significant. So there are significant extra colonic abnormalities that need to be evaluated.

FISHMAN: Which gets into the same exact argument with cardiac CT, in which, depending on which article you read, it's between 3% and 24% of cases. This is why the gastroenterologists last year said basically that they want to have two charges for virtual colonoscopy, one inside the colon and one outside the colon. So the radiologists can read outside and we want to read inside.

ZALIS: Interesting. There are roughly 7000 gastroenterologists in this country, and there are approximately 35,000 radiologists. I'm not going to state my own opinion on this just yet, but some have said, "So what? Let them read the colon. It's a public health benefit. Let them evaluate it, and people will have radiologists reading the extra colonic findings." As long as radiology is actively involved as a specialty, there's no danger of losing this to somebody else.

I think one of the questions that would arise in case of that split billing is the notion of self-referral. If gastroenterologists are buying CT scanners, to what degree are they self-referring? Are they being policed in terms of policy issues?

FISHMAN: The good news is that insurance companies do not want split billing. Otherwise, there will be someone reading the kidney, someone else reading the liver…there will be the spleen person, the adrenal person, the kidney person, the small bowel person, the spine person, etc. So it would be divided, and the cost would be up a thousand times, and diagnosis and quality would decrease

a hundred times. But I think the biggest challenge for radiology is really not to worry about the colonoscopists. Most of the GI guys I know are so busy that they aren't looking for more work. They have enough patients. So no one is waiting for someone to come through the door. The reason we can't do a program like the one in Wisconsin is that there's no colonoscopist who wants to leave two slots open. Why should they? They already have all their slots full.

ZALIS: In June 2000, there was a national Medicare carrier decision for screening colonoscopy. There are a large number of large-volume, relatively low-margin screening colonoscopy centers. Those individuals would feel very threatened by the advent of a competitive screening exam that they didn't control.

FISHMAN: Let's take one step back. If I'm a radiology group, and I want to own virtual colonoscopy, what do I have to do? I have the scanner. Then I buy the pump. Then what?

ZALIS: You need to go to a course, get trained, and do at least 50 cases supervised. You need to become familiar with a good software package (many are now available, thankfully). Then you need to develop a relationship with your local gastroenterologists. One good way to start is to offer completion colonography, which is a clear-cut win/win in terms of getting a program up and going. With this, when, for whatever reason, the optical colonoscopy and the standard program can't be completed, you offer same-day completion service via CT colonoscopy. This way, the patient does not have to undergo another day of prep.

We do this on a tech-driven program in our institution, and we offer basically a 1.5-hour turnaround time, with nearly 100% success. That's been very, very positive in fostering a collegial relationship between the two specialties. After that, once you get up to speed, you are comfortable and you have a base of gastroenterologists who are reasonably supportive. Then you need to get the word out to primary care physicians and educate them about this exam.

Finally, assuming you work in an environment in which you can get decent reimbursement, that is the other chicken and egg as part of this. I hope we will move out from a CPT category 3 code, get a proper CPT-1 code in the next year or so, and get a proper exam and billing code, etc. When that happens, you will see all of this begin to go the way Dr. Federle described.

FISHMAN: Is that what you guys are doing?

EARLS: We do just 2 or 3 cases a week.

FISHMAN: So you're not really pushing it.

EARLS: We lack a physician champion in our practice. We need one guy out there giving talks and developing relationships. We have multiple people who are trained to do it. But we don't have somebody out there selling it.

FISHMAN: We were part of the ACRIN study at Hopkins, and Karen Horton was the number-one proponent. We did a reasonable number of exams. But I would say that it is the most time-consuming study we do, not only on the read side, but also on the scanning side. You are scanning patients supine and prone, and you've got to prep them. Before you get the air in, we would have had 2 patients finished with other studies. So it really is a time-consuming study. That may be one of the resistances, particularly since there is bad reimbursement.

ZALIS: There are a number of things to think about. Once you get reimbursement more solidly in place, there are a number of simple implementations that could be done that people haven't done because they haven't been on the front line. For example, with the insufflation, I know one vendor had an MR gantry table that could decouple from the scanner and move from place to place. There's nothing that would keep you from insufflating patients outside of the exam room, which would take maybe 4 or 5 minutes.

Once they're insufflated, you then wheel them up to the scanner gantry. You make one gentle maneuver right on to the scanner, and you can scan them very quickly. Once you have the patient insufflated and prepped, the scan time in the room is not that great. But you need infrastructure and personnel training changes.

FISHMAN: In my experience at least, the pump makes a big difference. In the old days, we squeezed in the air by hand, and we never really knew if we did a good job. Also, with the pump, patients are pretty comfortable when the study is over. When you did it by hand, they were in the bathroom for 25 minutes.

ZALIS: Also, CO_2 is reabsorbed very rapidly, so patients don't have prolonged distension or cramping, which makes a big difference in comfort.

CT of the small intestine: Enterography and angiography

CT enterography and CT angiography outperform conventional barium studies and serve as a good complement to direct and capsule endoscopy.

Michael P. Federle, MD

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The small intestine is a difficult organ to examine by clinical or radiographic means. The upper gastrointestinal (GI) tract—comprising the esophagus, stomach, and duodenum—is accessible by direct endoscopy, as is the colon. The small intestine, however, is beyond the reach of most flexible endoscopes.

Capsule endoscopy is one alternative for the evaluation of the small intestine. It yields excellent endoscopic images of a variety of pathologies of the small bowel lumen. However, limitations in the field of view and frame rate mean that capsule endoscopy can miss a lesion if it does not capture an image as it passes through an area of disease. Crohn's disease, for example, typically does not involve the entire intestine, and GI bleeding may be isolated to only certain sites. In addition, capsule endoscopy is not easy to interpret. This capsule may take thousands of pictures of the small intestine, which necessitates tedious review.

Radiographic studies used for the evaluation of small bowel disease include the following:

- Small bowel follow-through, which involves oral administration of barium followed by fluoroscopic and overhead radiography;
- Enteroclysis, which involves nasojejunal intubation of the patient and active pumping of barium beyond the pylorus to distend the small intestine;
- Conventional computed tomography (CT), with conventional contrast agents; and
- CT enterography, with or without intubation.

Each of these techniques has advantages and disadvantages. Small bowel follow-through is time-consuming, especially in the case of poor peristalsis or partial obstruction. It achieves poor distention of the bowel, because the pylorus restricts gastric emptying. There are frequent blind spots caused by overlying segments of the small bowel as it twists and turns along its >20-foot length. In addition, small bowel follow-through offers no information beyond the mucosal surface of the bowel itself.

Enteroclysis is uncomfortable for patients. It can be time-consuming to intubate the patient and achieve bowel distension. It is associated with a moderate level of radiation exposure. Enteroclysis is, however, unequivocally the best test for detecting partial obstruction and subtle fold abnormalities or masses within the lumen.

Conventional CT is well established for the overall evaluation of the abdomen and pelvis, including portions of the bowel, the lymph nodes, and abscesses that may be related to bowel pathology. However, positive oral contrast medium impairs the assessment of the bowel wall and lumen, precluding visualization of abnormal mucosal enhancement and GI bleeding.

CT enterography delivers the same information in cross-sectional and multiplanar imaging as conventional CT scanning, but generally makes use of neutral or negative contrast media to distend the bowel lumen. Intubation of the patient is not necessary. Interpretation of this study includes multiplanar displays in axial, coronal, and sagittal views.

Recent studies[1-6] have compared CT enterography with ileoscopy, capsule endoscopy, and small bowel follow-through. In a study by Hara et al,[5] CT enterography detected twice as many patients with active Crohn's disease as did small bowel follow-through. CT enterography was found to be complimentary to endoscopy, whether direct or capsule, and was useful for detecting strictures of the bowel that might preclude capsule endoscopy. The authors noted that CT enterography could be performed rapidly and was easy to interpret.

Figure 1 illustrates some of the advantages of CT enterography over other techniques. This patient had undergone small bowel follow-through and conventional colonoscopy, both of which were interpreted as normal. The patient then underwent capsule endoscopy to evaluate the endoluminal bowel. It showed some areas of mucosal ulceration, but the capsule became trapped. Subsequent CT enterography showed a stricture of the small bowel. The patient required surgery to have the capsule removed.

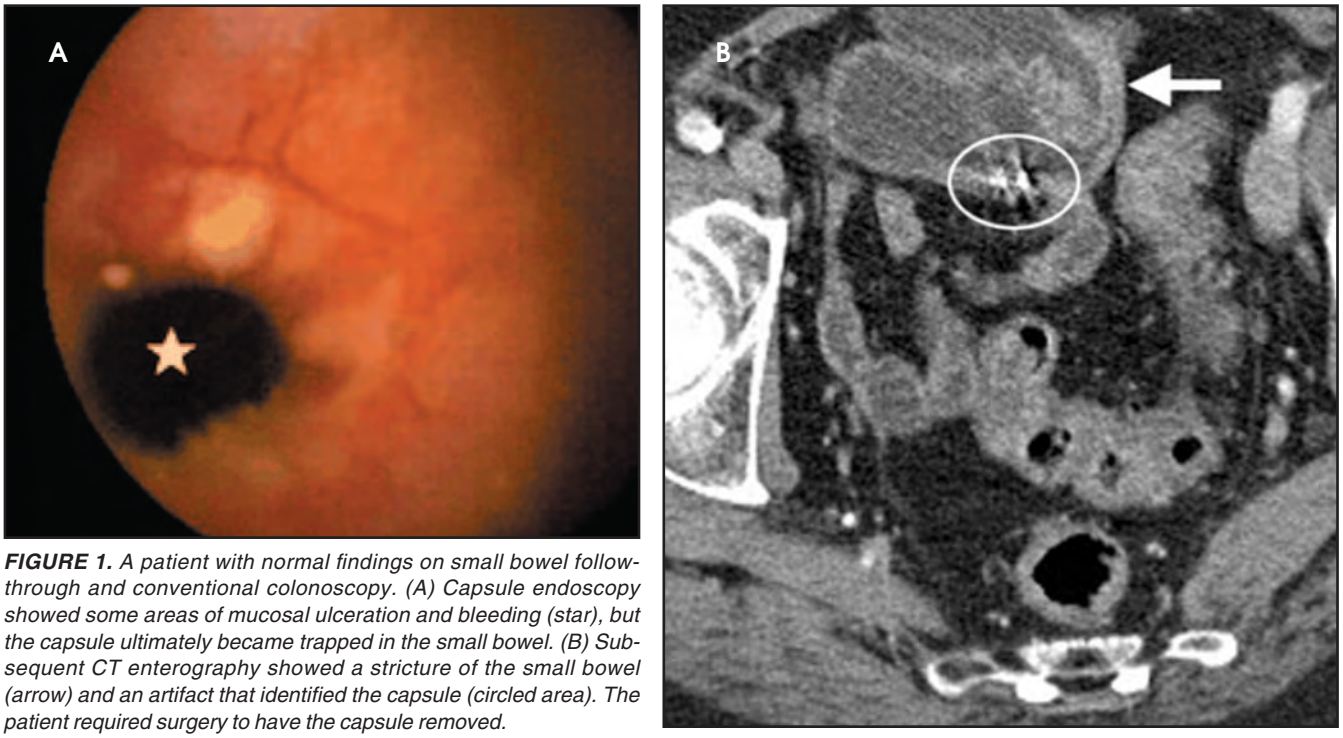

FIGURE 1. *A patient with normal findings on small bowel follow-through and conventional colonoscopy. (A) Capsule endoscopy showed some areas of mucosal ulceration and bleeding (star), but the capsule ultimately became trapped in the small bowel. (B) Subsequent CT enterography showed a stricture of the small bowel (arrow) and an artifact that identified the capsule (circled area). The patient required surgery to have the capsule removed.*

Contrast administration

For CT enterography at our institution, we prefer to use a neutral oral contrast agent, which does not preclude visualization of mucosal enhancement or GI bleeding. Water works very well. It is inexpensive, well tolerated by patients, and effective for distending the stomach, duodenum, and jejunum. However, water is rapidly absorbed from the small intestine, often resulting in suboptimal distention of the ileum and distal small bowel.

VoLumen (E-Z-EM, Inc., Lake Success, NY) is a commercially available contrast agent that consists of water, a suspending agent, and small amount of barium. This agent produces a degree of distention of the stomach and proximal bowel that is similar to that of water, but its lack of absorption has the potential to produce better distention of the distal small intestine. It does have limitations, however. Because many patients find the taste and consistency of this agent to be unpleasant, they may be reluctant to drink an adequate volume of the contrast material to produce the desired distension of the small bowel. In addition, the recommended volume routinely causes loose bowel movements or diarrhea very soon after the scan is complete.

For the evaluation of the upper small intestine only, the manufacturer recommends that patients drink a total of two 450-mL bottles of the agent, with a 10-minute interval between each bottle. We do not use this protocol, however. Water achieves the same results, is less expensive, and is better tolerated by patients.

For the evaluation of the complete small intestine, however, we do use VoLumen. Patients are given three 450-mL bottles, each of which is consumed at about 15-minute intervals. The last 150 to 200 mL is consumed just before the patient gets on the scanner. In addition, intravenous contrast is an essential component of CT enterography. It enables the evaluation of wall thickening, mucosal enhancement, the supplying and draining blood vessels, and the presence or absence of GI bleeding. We routinely administer 100 to 125 mL of intravenous contrast at a rate of 3 to 5 mL/sec, initiating the scan acquisition after a 60-second delay.

Certain medications may be helpful but are optional. Metoclopramide (10 mg given orally 75 minutes before the CT scan) stimulates gastric emptying. Glucagon (1 mg delivered intravenously just before the CT scan) relaxes the small bowel and slows emptying of the small intestine.

Crohn's disease

In our experience, CT enterography is quickly accepted by clinicians, who are well aware of the limitations of other techniques for the evaluation of the small intestine. When we first began offering this service approximately 2 years ago, we gave several presentations on CT enterography to gastroenterologists and other physicians. The referral effect was immediate, and since then, demand for this procedure has grown steadily on its own.

The evaluation of patients with known or suspected Crohn's disease is the most common indication for CT enterography in our institution. Signs of active disease include hyperenhancement of the bowel wall, mural thickening >3 mm, mural stratification, and mesenteric hyperemia, with engorged blood vessels—essentially the vasa recta—which are identifiable by a comb sign or a caterpillar sign. Abscesses indicate transmural disease, as does the presence of a fistula to the bowel, bladder, skin, or other organ.[1-6]

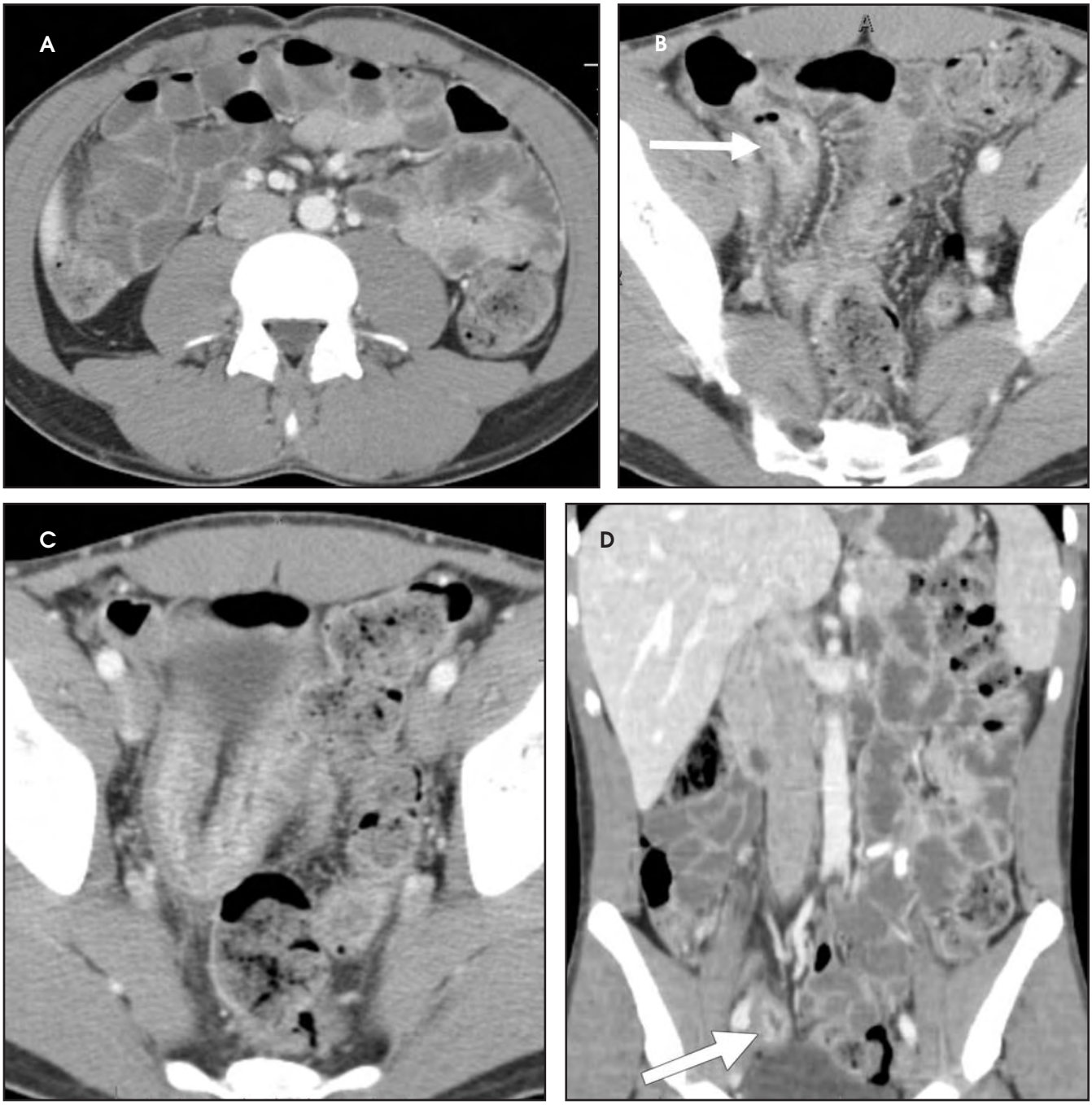

FIGURE 2. *A patient with early Crohn's disease. (A) The jejunum and ileum look normal at this level. (B) An axial section through the lower abdomen shows a segment of the distal ileum (arrow) near the cecum that is characterized by thickening of the mucosa, stratification of the wall, and engorgement of the vasa recta. (C) A more caudal axial section shows the thick-walled distal ileum. (D) A coronal view of the same bowel segment (arrow) shows abnormal thickening and enhancement of the mucosa and thickening of the submucosa.*

Figure 2 shows a patient with early Crohn's disease. On some axial sections the jejunum and ileum look normal; however, an axial section through the lower abdomen shows a segment of the distal ileum near the cecum that is characterized by thickening of the mucosa, stratification of the bowel wall, and engorgement of the vasa recta. Multiplanar reformats show a segment of thick-walled distal ileum. A coronal view of the same bowel segment shows abnormal thickening and enhancement of the mucosa and thickening of the submucosa.

We are often asked to determine whether patients with established Crohn's disease are having an acute flare on top of their chronic condition. Traditional fluoroscopic barium studies are very limited in their ability to answer this question. However, certain CT findings are reliable

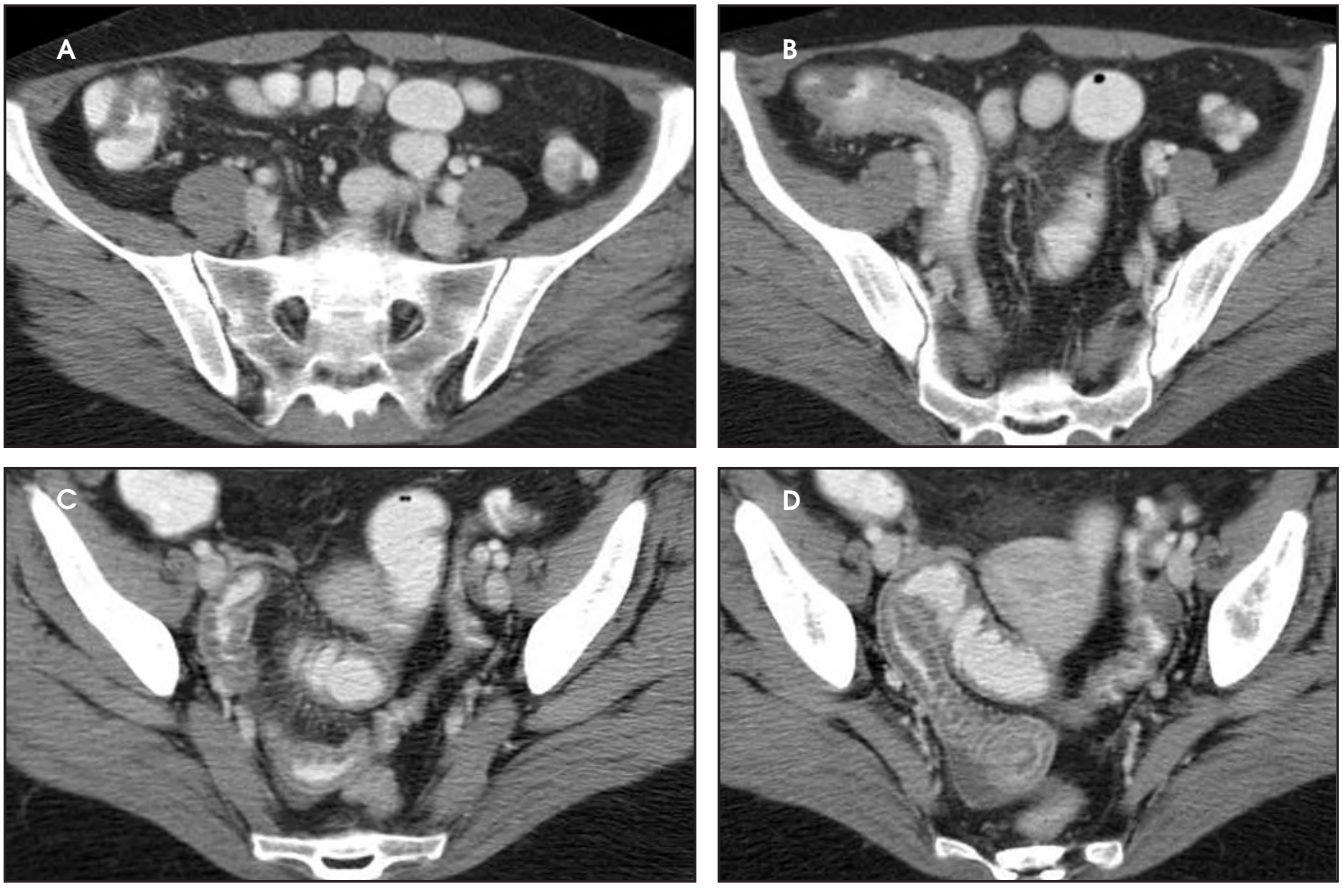

FIGURE 3. *A patient with an acute flare on a background of chronic Crohn's disease, indicated by (A and B) bowel wall thickening and luminal narrowing, and (C and D) mural stratification and hyperemia.*

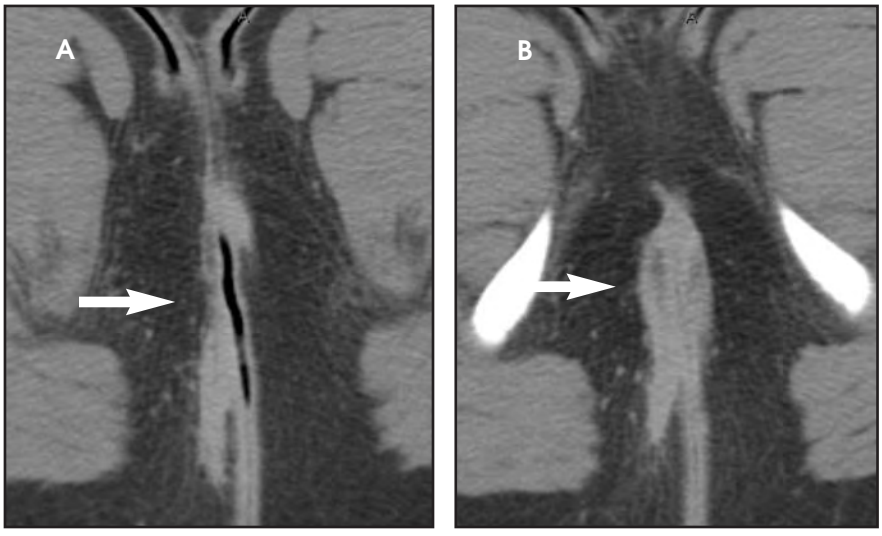

FIGURE 4. *(A and B) Perianal fistula (arrows) is a common feature in patients with Crohn's disease. (A) An axial section shows gas in the intergluteal cleft. (B) A more caudal section through the ischiorectal fossa.*

indicators. Thickening of the bowel wall, abnormal enhancement of the mucosa, mural stratification, and hyperemia are signs of acute disease (Figure 3). The development of a frank abscess also indicates active Crohn's disease. This is a critical finding that may signal an immediate need for surgical or interventional therapy. Fibrofatty proliferation is consistent with chronic Crohn's disease, and luminal narrowing may indicate either chronic or acute disease.

Perianal fistula is a common feature in patients with Crohn's disease (Figure 4). Fistulas to the skin may also occur at the site of anastomosis of the small bowel to the colon, following surgical resection. The patient in Figure 5 had both enterocutaneous and bowel-to-bowel fistulas. Because of a partial bowel obstruction, small bowel follow-through provided little information other than the presence of severe chronic disease with strictures and markedly delayed emptying. CT enterography nicely showed not only a dilated bowel but also a fistula to the skin and another from bowel to bowel.

Other pathology of the small bowel

GI bleeding

Bleeding from the upper GI tract, if it is reachable by endoscope, is well evaluated

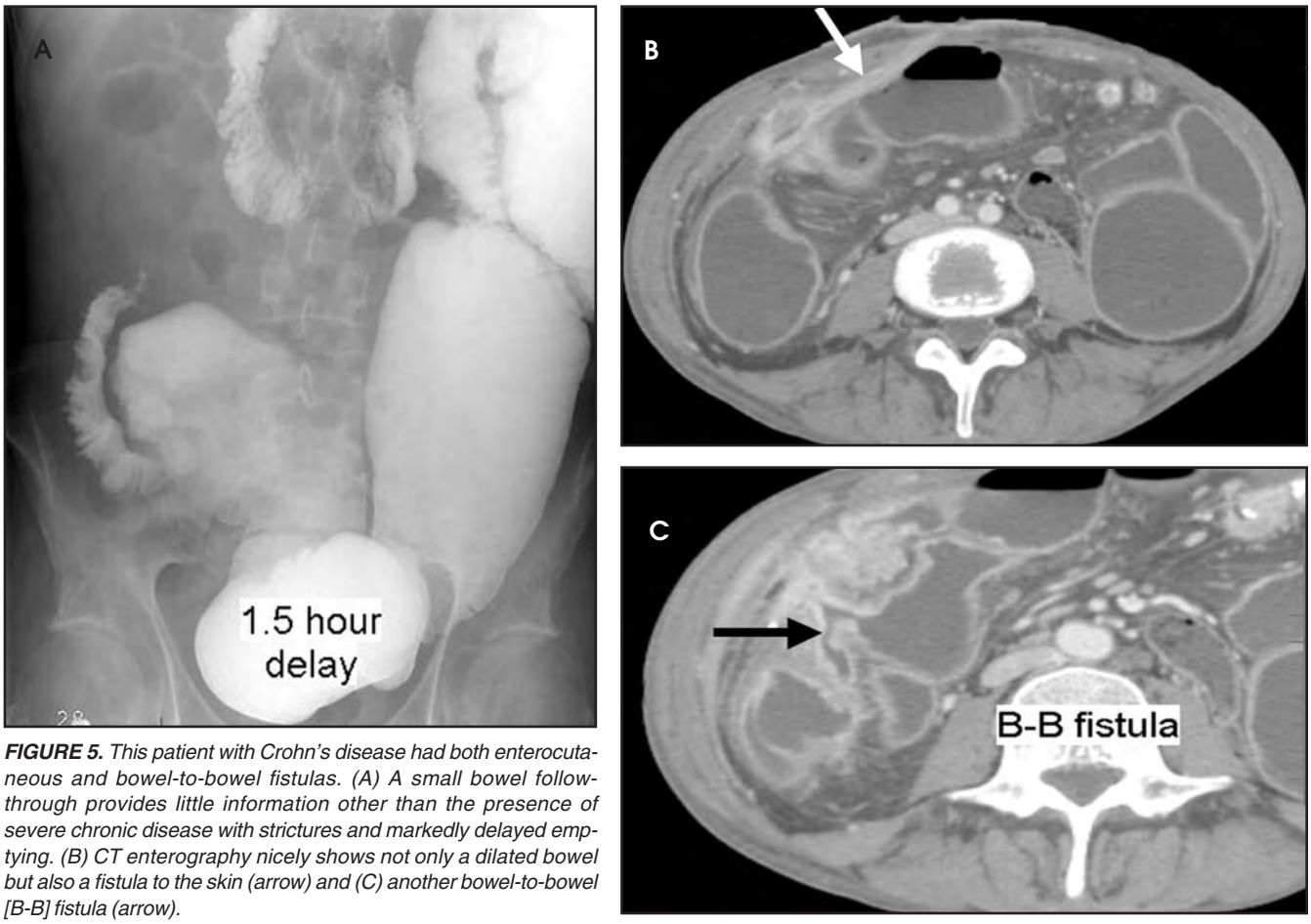

FIGURE 5. *This patient with Crohn's disease had both enterocutaneous and bowel-to-bowel fistulas. (A) A small bowel follow-through provides little information other than the presence of severe chronic disease with strictures and markedly delayed emptying. (B) CT enterography nicely shows not only a dilated bowel but also a fistula to the skin (arrow) and (C) another bowel-to-bowel [B-B] fistula (arrow).*

by endoscopy, as bleeding from the colon is well evaluated by colonoscopy. Generally, CT enterography has little role in the evaluation of such patients.

Gastrointestinal bleeding from the small intestine is less common but is difficult to diagnose by endoscopy or conventional imaging. CT enterography shows promise as a complementary study to capsule endoscopy in this setting. CT enterography misses some lesions, such as flat arteriovenous malformations that may be seen on capsule endoscopy. On the other hand, CT can show active extravasation of contrast into the bowel lumen. The evaluation of GI bleeding by CT is accomplished using the same protocol for CT enterography as has already been described.

Figure 6 shows a patient with spontaneous jejunal intramural hematoma as a result of anticoagulation therapy. The patient presented with abdominal pain and GI bleeding. CT showed massive thickening of a long segment of small bowel indicative of an intramural hematoma. The high-density infiltration of the submucosal tissue is typical of bleeding.

The patient shown in Figure 7, who was the recipient of a heart transplant, presented with abdominal pain and GI bleeding. CT revealed an intramural small bowel hematoma and a partial small bowel obstruction.

Sprue

Celiac sprue is an autoimmune disorder that is triggered by exposure to gluten and results in damage to the small intestine. It is characterized by an alteration in the fold pattern of the small intestine, including jejunal atrophy, ileal hypertrophy, fold reversal, and intussusception (Figure 8). Patients with sprue are also at increased risk for lymphoma and carcinoma of the bowel (Figure 9). CT enterography accurately depicts each of these features and complications.

Small bowel obstruction

Radiologists have several goals when imaging a suspected small bowel obstruction. These include determining its presence, its location, its cause, and any associated complications, especially ischemia. CT is much more accurate and clinically useful than plain radiography for these determinations.

The patient in Figure 10 presented with abdominal distension and pain. CT showed a dilated small bowel with a very thin wall. As in this case, the use of intravenous contrast material is critical to the proper assessment of patients with small bowel obstruction. Viable segments of the small bowel typically show brisk enhancement of the mucosa, whereas ischemic segments may show virtually no enhancement.

Closed-loop obstructions are well known for resulting in bowel ischemia. An additional sign of ischemia is the presence of ascites. A very late sign of

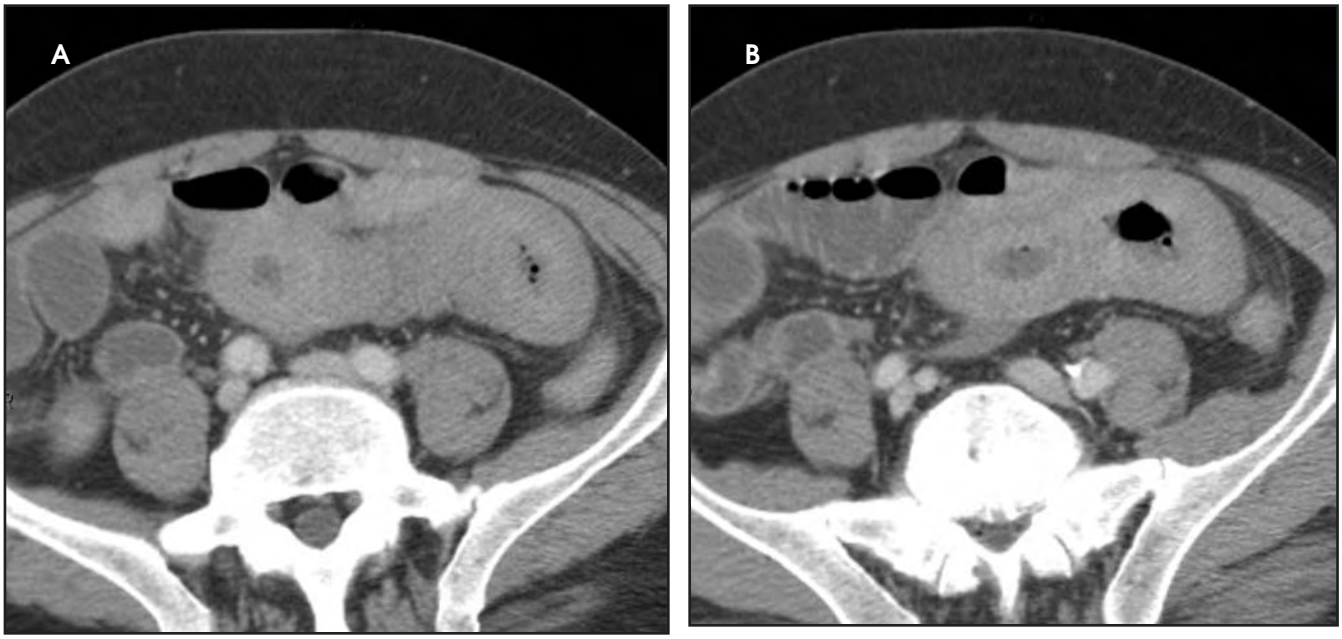

FIGURE 6. *A patient who developed abdominal pain and gastrointestinal bleeding as a result of spontaneous jejunal intramural hematoma, which was caused by anticoagulation therapy. (A and B) CT showed massive thickening of a long segment of small bowel, which is indicative of intramural hematoma. The high-density infiltration of the submucosal layer is typical of bleeding. (B) This image is a more caudal section than that shown in A.*

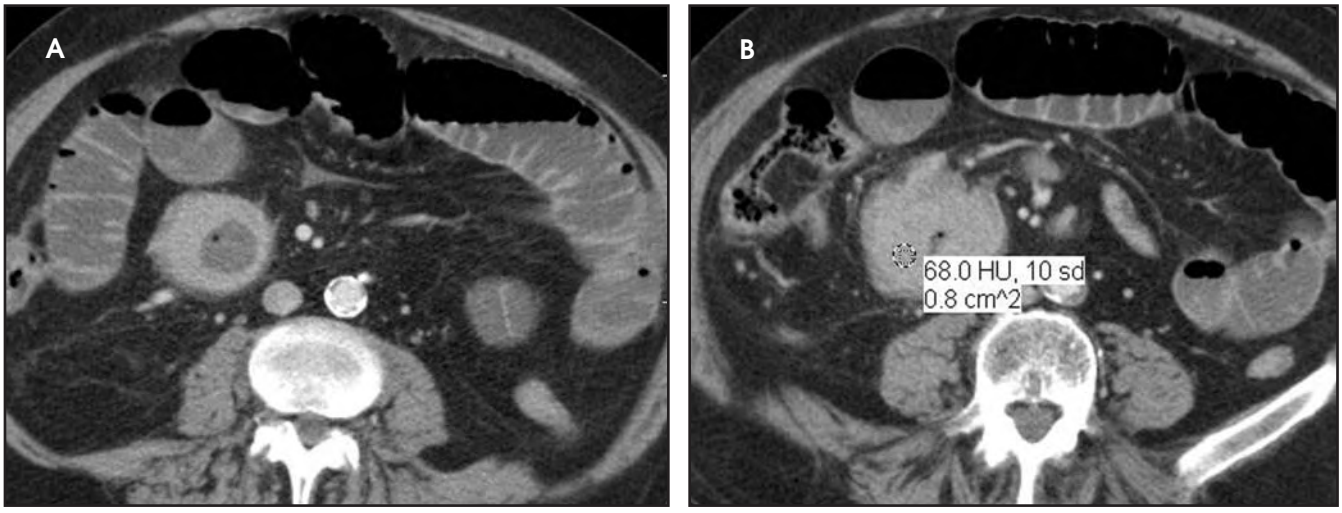

FIGURE 7. *A heart transplant recipient who presented with abdominal pain and gastrointestinal bleeding. (A and B) CT shows (A) an intramural small bowel hematoma and (B) a partial small bowel obstruction. (B) In the more caudal section, note the high-attenuation mural hematoma and the narrowed lumen, which caused the bowel obstruction.*

ischemia or infarction is pneumatosis within the bowel wall.

Conclusion

CT enterography will largely replace fluoroscopic barium studies for evaluation of the small intestine. CT enterography will not replace visual optical endoscopy for portions of the bowel that can be reached with an endoscope, nor will it replace capsule endoscopy. However, CT enterography will play an important role as a complement to capsule endoscopy.

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FIGURE 8. *(A) A patient with sprue and an intussusception (arrow). (B and C) CT showed a dilated bowel lumen and increased height of folds in the ileum.*

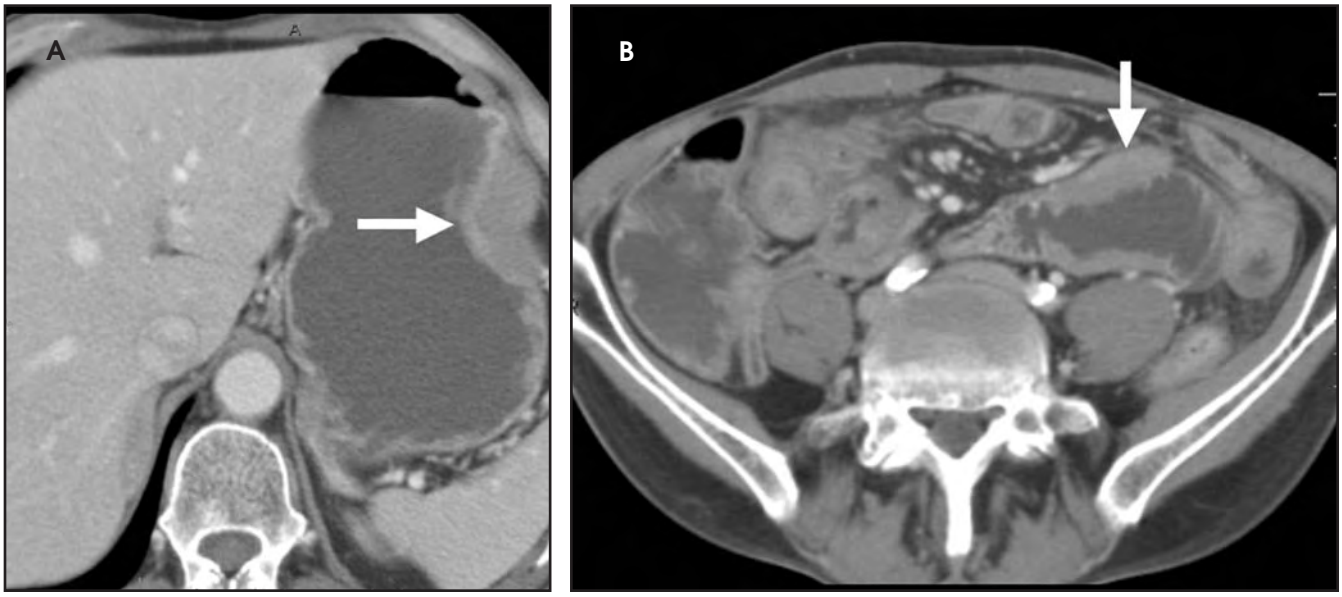

FIGURE 9. *A patient with sprue, mural masses, and lymphoma of (A) the stomach (arrow) and (B) the ileum (arrow).*

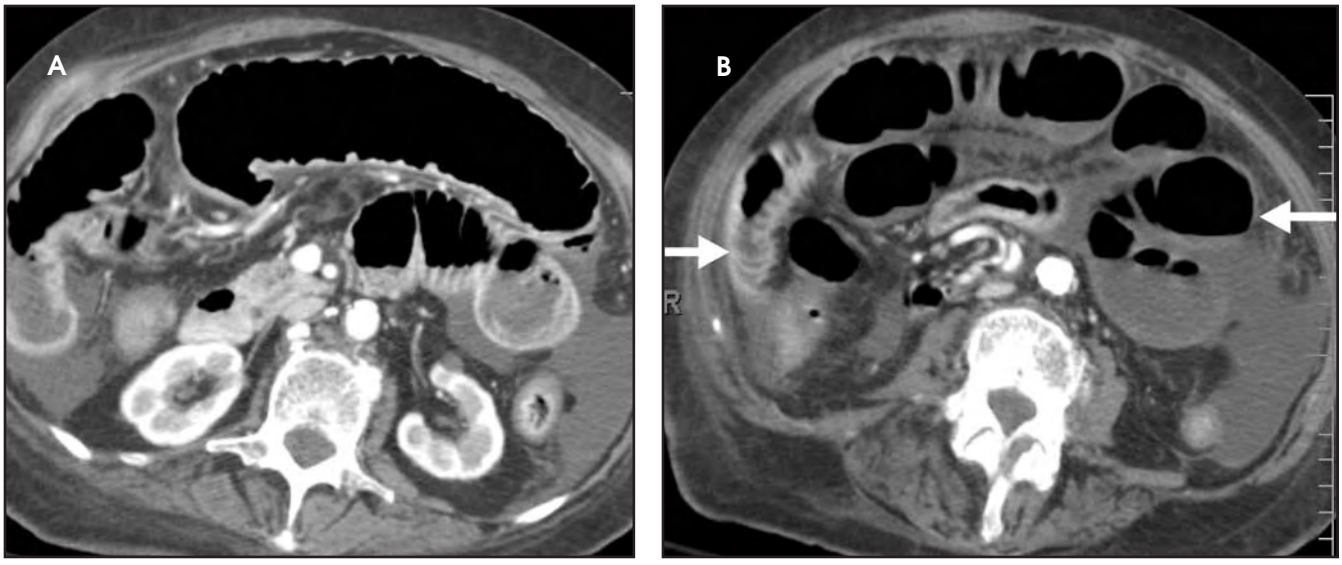

FIGURE 10. *A patient with abdominal distension and pain. (A) CT shows a dilated small bowel with a very thin wall. (B) Intravenous contrast enables visualization of both viable segments, which are identified by brisk enhancement of the mucosa (left arrow) and ischemic segments, identified by the absence of enhancement of the bowel wall (right arrow).*

6. Maglinte DD. Science to practice: Do mural attenuation and thickness at contrast-enhanced CT enterography correlate with endoscopic and histologic findings of inflammation in Crohn disease? *Radiology*. 2006;238:381-382.

Discussion

ELLIOT FISHMAN, MD: Mike, how many small bowel CT studies series do you do in an average week?

MICHAEL FEDERLE, MD: If you include the abdominal pain scans, not ER stuff, probably 6 to 10, I would think.

FISHMAN: We do a lot of them too. About your protocol, you said that whether you use water or or positive contrast solution, the key is IV contrast. What are your injection protocols and timing?

MICHAEL FEDERLE, MD: We don't do anything really fancy. We generally administer 125 mL of contrast on average; our range is 100 to 125 mL. We administer it at a rate of 3 to 5 mL per second. I think 4 mL/sec is perfectly fine. The timing depends on the age and cardiac status of the patient. So we actually use SmartPrep on a lot of patients. We'll put a cursor over the aorta and the upper abdomen. When we see it start to spike, we start scanning a few seconds later.

FISHMAN: Do you do many dual-phase studies?

FEDERLE: For the acute abdomen, we do not.

FISHMAN: What about for a GI bleed or for Crohn's diease?

FEDERLE: Honestly, I have not. We're probably doing OK. We're deliberately not timing this strictly as a CT arteriogram. The scanners are fast enough now that I really don't want to be scanning at 18 or 20 seconds, when I have only arterial enhancement. I want to see those veins and I want to allow for bowel wall enhancement. Particularly if I am scanning a patient for abdominal pain (and you know how incomplete the histories we're given usually are), I want to be able to see the kidneys, the liver, and the pancreas. So I don't want to scan during the strict arterial phase of imaging.

FISHMAN: I know you mentioned about getting almost routine coronals. Beyond that, do you do much 3D imaging for vascular mapping in the small bowel?

FEDERLE: We do when our attention is drawn to that by the clinicians or by our observations. We are not routinely doing a 3D map. I do believe that coronal and multiplanar imaging is absolutely essential if you are going to try to evaluate small bowel disease. It's just so convoluted that trying to view it in any 1 plane is just not adequate. Unlike the situation with CT colonography, however, to date, we have not used endoluminal views. I don't know whether we'll come to that or not.

FISHMAN: When you do the MPRs, do you do sagittals also?

FEDERLE: Coronals are really the go-to procedures. But I'll do what's necessary to convey the information. Let me tell you a little anecdote about that. We had a patient with chronic intermittent abdominal pain. I'm looking at the axial CT sections with a surgical resident. I said, "Your patient has a high-grade mechanical obstruction lesion. It's right here on the distal ileum. It's probably adhesive. I'm quite confident about that." He took the information upstairs and he came back and said, "Dr. So-and-So wants an enterocleisis."

I said, "That makes no sense. I am giving you the information you need." He said, "He looked at the images, and he doesn't find it convincing." So, I took the same data set and did a straight coronal, which wasn't really quite ideally in the plane of imaging. Then I created what wound up being an off-axial section that showed exactly the plane of the thing. I put a big arrow on it and labeled it,"This is the stricture." I sent it back and he then said, "Oh, now I am convinced." Then he took the patient to surgery.

FISHMAN: With all this postprocessing, particularly in GI, as much as it's helpful for us, I think it is particularly helpful for the clinicians because CT is very difficult when looking at small bowel obstruction, in terms of being precise. It's kind of funny; it's like a step backward, but doing coronal or 3D is becoming like a plain-film small bowel series. But it is very valuable for them. Small bowel imaging is a very big growth area. I think it is a difficult area, between all the stuff in the ER with acute abdomen pathology and dedicated small bowel studies. We also do a lot of scans for Crohn's disease. Are you using it for management in the same way?

FEDERLE: Absolutely. We have a huge Crohn's clinic, and I alluded to some of the factors that they ask us about. "I know my patient has Crohn's, I'm not asking you that. I'm asking you, is he having an acute flare? Is he having a complication that requires surgery? Do I need a change in management?" etc. So identifying those signs of active disease or complications that demand intervention (such as high-grade stricture, bowel obstruction, abscess, etc.), is a really key feature in the management of these patients.

FISHMAN: In some of the cases, you used water as a contrast agent, and in some you used positive contrast. Do you have some rules to determine when you do one or the other?

FEDERLE: It depends on how the patient is sent to us. If I know that I am evaluating someone with Crohn's disease, and I'm looking for activity or for possible complications, or if I am evaluating somebody with GI bleeding, I will definitely use a neutral contrast agent. Conversely, many patients came to me from the emergency room and the only information we have is "abdominal pain of unknown etiology." For those patients, we use positive contrast material. In the patients who have an abscess as a complication of Crohn's disease, the positive contrast sometimes makes it easier to perceive what is bowel and what isn't bowel, as opposed to the neutral agents.

FISHMAN: I agree.

Panel discussion

Moderator: Elliot K. Fishman, MD

ELLIOT K. FISHMAN, MD: We've talked a lot about the training issues for each of the applications. Right now the residency program takes 4 years, the same time it's always taken. I would guess that very few residency programs train residents in virtual colonoscopy. Do you train your residents in it?

MICHAEL E. ZALIS, MD: They just rotate through—it's primarily fellow-level training.

FISHMAN: The same thing is true with cardiac imaging. We are in a situation now in which we have new technology—including colon and cardiac CT–but we are basically not training the residents in these studies. The fourth year residents are all doing what they are doing. This year they voted to theoretically postpone the boards for 2 years at the Association of University Radiologists. In that case, 2 years after you finish residency, you will take the boards. The nice thing about that would be that the residents would be real residents again. Of course, private practice people will complain, "The residents are studying, and you are hiring non–board-certified radiologists."

ZALIS: Then they will disappear in their second year to go take the boards.

FISHMAN: With the programs we have now, with these new technologies (eg, cardiac, colon, and everything else coming along), how are you training people so they don't go out inexperienced?

What are others guys doing in your residency programs? How do you approach GI imaging training for residents?

MICHAEL P. FEDERLE, MD: We try to get the residents as involved as possible. It's interesting—we see almost self-stratification among the residents. Some of them have clearly decided that this is important in their future, and we'll see them spend a lot of extra time learning cardiac CT or other applications. Others basically want to pass the boards, and if it's not on the boards, or if it is not in widespread use, they are not particularly interested. Or maybe this is to their credit, if they are looking at a career in neuroradiology or something else specific, they may think that these techniques are less important for them.

But our residents certainly finish with a wide variety of skill sets. We do insist among our fellows that these become acquired skills. Frankly, I think one of the attractions of doing a fellowship is that you do get a chance to spend some more time perfecting these things. Something I've observed ruefully over the years is that some of our residents come out of the program saying, "We're really trained in abdominal imaging. Now, we didn't get very good training in [fill in the blank], so I'm going to pursue a fellowship in that."

So sometimes I feel that we're shooting ourselves in the foot by doing a really good job of training the residents in abdominal imaging, so much so that some of them don't feel the need to pursue a fellowship in it.

JAMES P. EARLS, MD: We actually have the same issue in the chest and cardiac world. They feel that they've gotten such a strong background in pulmonary and cardiac imaging that they don't think they need to do a fellowship. At least that's what they tell us!

FISHMAN: I have heard that the number one fellowship is musculoskeletal. How is that possible?

FEDERLE: It happens because of private practice. We're really struggling with this in our practice. Most patients get their MSK MR scans in outpatient facilities, so they are not coming into the mother ship where the residents are doing their rotations. So we have residents always saying, "I'm just not getting adequate exposure to MSK. But that's a big issue in private practice. I've really got to read those knees and shoulders, so that's what I need to do a fellowship in."

FISHMAN: A lot of the biggest fellowships are fancy private practice groups in California because they just have massive numbers of knee studies. Nobody wants to see tumors like we get at any of our institutions because they are so rare. It's those knees and shoulders they need to see.

CHARLES WHITE, MD: It's their mindset. I don't know what fraction of your residents go into academics, but like ours, it is probably a small minority. If you are interested in private practice, then MSK is certainly one of the things to think about. It is a bit of a misconception, I think, because the practices aren't just looking for musculoskeletal-fellowship–trained radiologists. But that's the urban legend.

ZALIS: We have to remember how the process went with a lot of new things in the past. For example, mammography started off as part of musculoskeletal imaging ages ago. When there was sufficient demand and data, the American Board of Radiology declared it was a standard part of our practice, or it would be. Then they mandated it on the boards. Everything else followed from that, and the curricula of various residency programs were rearranged. That all went through many various committees to decide how much mammography should be taught. As our specialty continues to evolve and grow, there will be further realignments of the programs. For example, our residents are not doing as much barium enema as they used to,

simply because the demand for that has decreased.

FISHMAN: It is very different now than it was for all of us who trained in the Dark Ages! I have calculated that I did more floruoscopy in 1 day as a resident than today's residents do in 4 years! But we have to understand that societies and the ABR move very slowly, and this technology is very fast moving. Radiology could be left off the table, if we don't rapidly adapt this technology.

The reality is that Jay needs people to do virtual colon today. Mike is hiring people to do it today. How do we meet the demand today?

The board will eventually agree to it. It's hard to imagine that someone can come out of a residency program in an institution that has experts in cardiac imaging or virtual colonoscopy and not be trained in that technology. How can you justify that you would put people out in practice who aren't experts in that?

ZALIS: At this point in time, the residency program structure is essentially dictated by the mandates of the ABR, and colonography is not on the board exam. So, right now, it doesn't have the justification to compete for time with everything else during residency. In response to the question of how you hire somebody who knows how to do colonography is that there are, thankfully, numerous very good CME courses available.

People take very seriously the idea that people who are going to get into this need to be trained properly. We want to avoid some of the problems that occurred with mammography in its early days. When people saw a gold rush, they all jumped in. There were 17 different protocols, and there wasn't a good standard of how to report, how to perform, or how to interpret the studies. There was, frankly, a lot of malpractice in the early days. What was the result of that? For numerous complex reasons, we have MQSA—federal specification of exactly how to do mammography in this country. I think many people would like to avoid a similar set of circumstances with colonography.

FISHMAN: But it's hard to imagine that we're not training people what they need to do in practice. In many ways, we need to do this to preserve radiology's eminence in these topics. Saying they have to go to a course for a few days is probably not good enough.

ZALIS: It's not good enough.

FISHMAN: We've talked about new technologies and you speak at many courses. What are your recommendations to people already in practice? What do you suggest to people who feel they haven't mastered the subjects they need to master? There's so much to do, and there's so little time.

FEDERLE: At the risk of shooting myself in the foot, I don't think that merely hearing a 30-minute talk at a course can be enough. That can only whet your interest, and it can buff up some existing knowledge. But you certainly need more practical experience with a lot of these things. Frankly, the best way to do a lot of these techniques is just get in there and do them. For CT enterography, somebody could go out tomorrow and start doing it and could actually do a pretty good job of it. It does not demand a lot of fancy software or extra equipment.

For other kinds of procedures, such as cardiac CT and CT colonography, there's no substitute for rigorous learning: sitting down, reading a lot of cases, and really seeing how a program is run. Some of these are programmatic issues. At the best places I know, patients don't just show up randomly on your everyday schedule. They have a system for how to handle these patients. It's good to go spend some time at a place that has real-world experience with this and do it there.

EARLS: I totally agree with that. The ACR may set up something along those lines so you can go and work on a workstation and spend 3 to 5 days learning "hands on" on the workstation. You can do that whether it's cardiac imaging or CT colonoscopy.

Another possibility is that a lot of places are doing observerships, and we're doing this as well. Any place that is doing a fair business in any one of these imaging techniques can set it up. Each program has different arrangements, but people are allowed to go in for a dedicated period of time, whether it is a few days, a week, or perhaps even longer. The observers watch the radiologists in those sections work because they have as much experience as anybody. Then you can develop your own style. But at least you learn while you are sitting there, watching the workflow and the protocols. There should also be some dedicated lecturing and some materials. Increasingly, observerships are one way to bridge that knowledge gap.

FISHMAN: It's a challenge. Having done observerships in the past, I can tell you that it is a killer. As Mike said, we don't want to dismiss those 30-minute lectures because it's a good way to reach a lot of people. But at all of our courses that we run from Hopkins, every one of them now includes workstations. They physically have workstations there. Part of our 3D meeting is that you have at least a minimum of 2 hours of training. You can't learn everything you need to know in 2 hours. But at least it is a way of getting started with expertise. Many people—radiologists maybe even more than technologists—are afraid to touch workstations. This has been the story for many years.

I do think it's a little bit of an age issue as well. I notice that the residents, once they have a thin client or its equivalent and the tools are available to them, they routinely use it. For them, it's very intuitive. The more senior radiologists have done things the same way forever, the less likely they are to change.

FISHMAN: What are you doing, Mike, with your program?

FEDERLE: Realistically, Elliot, my observation is that, even in a private practice, people are getting increasingly subspecialized. Within a large group, as we heard Jay allude to, there's a champion or there are several champions for cardiac imaging. He probably also has champions within his group for other subspecialty areas, not just by organ system, but even for particular modalities within that. That's the way I see it going.

It's like what happened in surgery when laparoscopic or minimally invasive techniques came along. Surgeons out in practice who didn't have that training in

residency said, "I now have to learn how to do a laparoscopic cholecystectomy, or I'm going to be left behind."

Similarly, now in a big pancreatic surgery place like you and I have, people are doing laparoscopic partial pancreatectomies. Very few people learn how to do that during residency. But if somebody says, "I want that to be a skill I can offer in my practice," they have to get the training to do that. I don't think that's going to happen in a routine general surgery residency. Some of these things are probably not going to happen in a routine radiology residency in 4 years.

WHITE: You can see it evolving in cardiac imaging. Roughly 3 or 4 years ago, residents weren't learning any cardiac imaging, but now there's a virtual cardiac section. I actually write some questions for the test, and I'm talking about the oral boards as well. There's an increasing shift toward asking about cardiac CT. There is definitely a wave in the direction of where the technology seems to be going and where the practice indications are.

For virtual colonoscopy, it may not be its own section. But if it becomes widespread enough and accepted enough, there will be a wave in that direction. It may not take all that long. The simple word to the residents that they may be shown a virtual colonoscopy case would be enough. That's all it would take.

FISHMAN: The programs have to be willing to do it. This is the first year in our fellowship that we've given them 1 month of 3D imaging, which includes colon, cardiac, and regular 3D imaging. During this month, they are not on the schedule.

DEANN HAAS: Something we have to worry about a little bit too is what we saw with cardiac CT and training courses. More and more people are doing it, and requirements are coming out. There have been physicians who have gone to a training course, and very quickly they open up a new course. They just learned how to do something, and now they are teaching other people to do it. But they're not ready to start teaching. I think there should be some type of regulation on who can be a trainer versus who is not a trainer.

FISHMAN: You don't believe in the "See one, do one, teach one" technique?

HAAS: They are actually going to start policing it a little bit more. You will have to be a Level 3 trainer, prove that you've done all these cases, and that you can read all these cases. I think it will have to be for everything.

FISHMAN: What are the challenges? You train people at least on a basic level. What can you suggest?

HAAS: We offer what we call master's courses for physicians. We find some key physicians who are doing cardiac and colon actually doing a master's course. I'm a technologist by training, and I'm certified. In theory, I can train technologists. But we don't have physicians in our practices. So we can't physically train.

We work with our clinical partners and set up accredited courses. They provide enough of the workstations or scanners at their facilities so that physicians can actually go train. We also sponsor a lot of CME courses. But we can't do much more than that because we don't have physicians to do the actual training.

FISHMAN: This could be an opportunity for vendors who are looking to invest in the radiology community. Jay, Charlie, and I participated in cardiac CT training with the Roentgen Ray that was sponsored by GE, for example. There will end up being 2000 people trained, but it's only a day and a half. You could argue that's not enough. They also sponsor 9 programs through Hopkins and they will train 2000 people also. Is this a way to provide training and to allow vendors to cultivate relationships? One way to develop relationships might be in residency, if they take residents from programs and train them in virtual colonoscopy, for example.

ZALIS: I would argue that basically the board follows practice, and practice follows reimbursement. Effectively,when you get reimbursement, you will have a demand that, in the short run, the CME courses are going to try to fulfill, even if imperfectly. Then, if you start to see this study rapidly emerging in terms of increased utilization across the board, that's what the ABR will see. Then over some period of time, in their own wisdom, they will adopt it.

FISHMAN: We agree. We've been running 3D courses for 10 years, so we've been waiting for the board to agree that 3D imaging was good. But I think it may be an issue for radiology to address. I don't think we can wait for the board to redesign the residency program. That could take 5 years at least, right?

ZALIS: I agree.

FEDERLE: At the risk of being self-serving, in CT colonography, you and I have been involved with the Society of GI Radiologists over the years. They have taken this on as a real cause to help get this imaging out there. We need to be on the forefront, even before reimbursement issues are settled. We are going to run some regional courses with this sort of training in mind, not just didactic lectures. People will sit down at workstations, talk to experts, and talk about how to set up a program. It is a really different orientation, and it will be dedicated to that single topic. We will be looking for corporate sponsors. Various corporations are already sponsoring similar sorts of sessions, maybe within the context of a larger society meeting.

FISHMAN: With cardiac and colon imaging, it's easy to lecture about things. But it is more difficult to organize the hands-on training because there are 5 or more workstation vendors, so you can't train everyone on the workstation they will actually use. As far as I am concerned, learning on a workstation that is not the workstation you will use is a waste of time. You can get some concepts down, such as what does it mean to render. But so much of the learning is really about where the buttons are and how to drive the tool.

FEDERLE: You and I are involved in the American Roentgen Ray Society and we understand their philosophy of sponsoring regional meetings on these hot-topic issues. But I think it's probably going to be impractical. I'm running a PET/CT meeting and there will be some meetings on CT colonoscopy. It's probably impractical to have 4 different vendors

of PET/CT units there to demonstrate their workstations. I generally agree with your statement that it's better to learn on the workstation that you are going to be using. I would hope, in fairness to all of the manufacturers, that radiology societies make an honest effort to reach out to all of the various manufacturers to explain the plan: "We're going to be doing 5 regional meetings on PET/CT. We're going to be doing several on CT colonoscopy."

Several of the cardiac imaging programs give manufacturers a chance to sponsor meetings and then promote the sponsorships. Maybe potential registrants can decide that it makes sense to sign up for the meeting sponsored by the manufacturer of the equipment they use.

WHITE: We are really talking about 2 forms of education. The initial introduction that can be provided in a 30-minute talk at a meeting. Everyone needs that. But then we also need hands-on training, and I frankly believe this has to be more extensive than a couple of hours. To a degree, it should be vendor-specific, presuming you know which vendor's products you will use. But I think both types of training are necessary.

FEDERLE: The format we're using for the Roentgen Ray–sponsored meetings (which we'll probably also use for the Society of GI Radiology) will be day-and-a-half meetings on a specific topic. Is that enough? I don't know. For some people, it probably is. Others will need some additional hands-on experience, which might come from the manufacturer of the equipment that they are using. But I think that will be a good head start to put this into your practice, as opposed to just hearing a few lectures on the topic at a general radiology meeting.

FISHMAN: There is definitely no downside. I think it is very important, particularly with colon and cardiac imaging, to have good data sets to work with. The best way to really learn is to do. Each site should get several CDs of data sets from their equipment manufacturer, and they should get a booklet with the answers in it. Once you have the data, you can play with the case. It would be very easy for the vendor to provide a second set of the cases that has the answers marked. For example, they could have the polyps circled and findings labeled. You look at the data yourself and interact with it, and then you could see the answers.

Karen Horton is our representative for the ACRIN CT colon study. I think they will really do very well because of the way they set up the sites. For most trials, you just sign up and promise to deliver the patients. In this trial, they made the participating radiologists take a test, and they had to pass the test with a certain score. It doesn't guarantee that you are great at it, but at least you had to meet that criteria. They also offered training in advance.

It is a good way of doing things. Right now, with the ACR, you have to do 50 cases. But you don't have to get an A; you just have to have seen the cases. In some ways, it's really not as good as it sounds—you could have slept through 50 cases!

On the other hand, it would be a good contribution if your equipment manufacturer gave you 50 cases that included some high-grade stenosis, normals, variations, etc. Then you have to just do them as they come. Once you've gathered the cases, it's really a low-cost idea to reproduce cases to distribute on CDs or post on the Web.

FEDERLE: I totally agree with you. I don't see any reason why the different manufacturers couldn't set up a learning lab at their location so radiologists could practice on their equivalent with real data sets. The data can be made properly anonymous to be HIPAA–compliant. The vendors don't even necessarily have to do any sort of certification. But I've never understood why they don't do that.

Years ago, I actually asked our CT vendor, "What would it take for me to come up to CT and spend a day or two learning a certain new technique?" They said, "You are a good friend of Dennis Foley's. We'll just send you over to spend time with Dennis." Dennis is a good friend of mine, but I didn't want to take time out of Dennis's busy day to instruct me in this. I would have been much happier in a little learning lab going through a structured course about how to learn it. If McDonald's can hold Hamburger University in Chicago, there should be something equivalent on the imaging side!

FISHMAN: Siemens has a North Carolina training center, where people can sign up for courses. The virtual colon study was done at a GE training center in Milwaukee, I believe. Equipment is expensive and if you need 10 or 20 workstations to hold training, you can't be popping them all over the place. You need a place to keep the workstations.

WHITE: A lot of the companies are farming training out to various academic or nonacademic places where they are running courses.

FEDERLE: Some of these places are probably doing this very well. But some of them are probably not doing it very well at all. When I was at UC San Francisco for 11 years, we had a very active visiting fellowship program. Some of the faculty were really good at interacting with the visitors, and some were really bad. Some visitors really learned a lot from it, and others probably came away learning nothing after a very expensive week or two there.

I was running one of those visiting fellowships there. I can tell you that when you are trying to do it in the midst of a busy practice, you really sometimes have to force yourself to spend time with the visiting fellows, even though they have paid a lot of money to be there. It takes you away from other department responsibilities and your pager is going off, and your cell phone is going off.

FISHMAN: We did the visiting fellowship. Some places do it very well. If you are going to do it, you have to do it as a business, and you have to have people who have the time. It can't be handled as if you are doing the person a favor. Right now, it's very variable. You need a learning center.

Any institution can make money on it. They asked me at Hopkins about starting a program. I told them that if they wanted to do it, they needed a room, an assistant, computers, and the data sets from those 50 cases. It has to be built up. If you wanted to do it, you have to look at it as a

profit center, and you need to make a major capital investment. I think that places that did it as a business, like the University of Pennsylvania, had learning centers. They had a person who would make sure everyone was happy, the cases were there, and the equipment was there. It's not a trivial thing, especially because of the cost of equipment, space, and people. The people may be the most expensive cost.

If you are going to do this, you have to do it as a business if you are really going to do it well. There's nothing wrong with doing it as a business, if you do it well. You also have to work with people's schedules, so the faculty who are supposed to teach are there when you have participants scheduled! We all have busy schedules and travel to meetings. If you are at an institution that says we're going to do this 4 times a year, then for those 4 weeks the relevant faculty have to be here. Then you could do it. The staff should be off the department schedule and should each have half of an afternoon just to deal with the visiting people.

It can't be done by the seat of the pants. That's a challenge, because it's very hard to get good hands-on training. I'm sure we've had the experience after you give a lecture, 10 audience members come to talk to you who want to spend time with you. Half of my e-mails are "Can I come?" It's not a matter of money. But you just can't do it all because these days, none of us have time to breathe, let alone teach others. I do a lot of 3D, but the reality is that at times I need to be doing it by myself to get finished in a timely fashion.

WHITE: What do we recommend for people who are interested in starting a cardiac CT program of their own? I would say that two elements are absolutely essential. First, you must to get a good solid introduction, which ideally should be primarily, if not completely, dedicated to cardiac CT. By that I mean dedicated talks on the entire range of topics of cardiac CT. Ideally, you should also get the experience with 50 cases from that.

Second, it is also really important that you spend hands-on time with the vendor of your choice. This can be done in an informal way or in a formal way. So the first part is the learning part, which helps you see the breadth of disease. Then the second part is getting real hands-on experience. It's important that we do not rely only on specialized technologists, but also that we can do it ourselves.

FISHMAN: We've had a lot of discussion today about cutting-edge hot topics in CT, including cardiac and colon imaging. One thing that is clear across all applications is that scanning is one part, and postprocessing is the other part. What are your recommendations in terms of training on postprocessing techniques?

HAAS: When most people get a new scanner, especially if they go from one vendor to another, they don't believe they need training. If they are scanning on a 4-slice, 8-slice, or 16-slice scanner, they think they can just move to a 64-slice. That's why we see the customers using 64-slice CT as if it were a different scanner, because that's what they are accustomed to. The site has to be prepared when we come in to train and to actually get dedicated people to do the training with.

We are asking our sites to get "super techs" who we can train, so they are then trained to train their staff. You can never train the whole staff at once. If you are going to do cardiac imaging or CT colonoscopy, you need to actually have the patients there to have these procedures.

Often, when trainers come in, the sites don't have patients. With cardiac imaging, we recommend that the doctors take time with the technologists who want to learn how to do cardiac imaging. They don't know the heart parameters, and they don't know ECGs. But if you spend time with them first, they become better at scanning. When techs get the new equipment, they are very excited to learn the new technologies. The other thing we've seen is that a lot of sites try to bring in a nuclear tech to be a CT tech, but their skill set is a lot different.

For the physicians, I would recommend going to masters courses. It's a little time away up front. But when they go to a course (for colon, cardiac, or any advanced application in the future), the benefit is that they have dedicated time to sit there. They can spend time to really learn the application, without their pagers or cell phones going off. The people who do this are the ones who are really doing well in cardiac and colon imaging.

FISHMAN: One of the biggest things about doing colon or cardiac imaging is that it's a matter of seeing a bunch of cases. Seeing a picture of a polyp or of a stenosis in a book is not the answer. You need to be able to start from zero and find that polyp or find the stenosis. Do you provide data sets?

HAAS: Yes, the workstations come with a couple cases. For colon imaging, we have a case study library that was developed with the Mayo Clinic. It includes 30 or 50 cases with the exam itself and the results from the physicians. So they can go in, and they have scorecards for testing. From our clinical trials, we did CT cases, so they will have CT and cardiac cases.

We are also developing training guides with our physicians. They will explain all of the steps from step 1 through reading. For instance, if they get new techs, it's a baseline guide so they start to understand how to do the procedures. So we're in the works to do that. Typically we did just come out with application staff to do the training. But now we're developing more stay-behind tools, so they have a guide for any new staff or if they forget something.

FISHMAN: I know you do a lot of training and you do a lot of meetings. What do you think is the biggest problem people have in doing cardiac?

HAAS: It differs from site to site. Two of the biggest things that I hear are concerns about reimbursement and education. After that, they are worried that they will lose the technology. I still cannot get the hospital that I trained in to start doing cardiac imaging. They have 3D CT scanners. But they think, "I'm going to lose this in a couple of years, so why start doing it?"

Look at Dr. Earls and yourself—a bunch of people have developed successful programs. I don't think they will ever lose that. We might have to do some things with marketing. How do we teach

the radiologists how to market themselves and their skill sets to the referring physician? One of our groups hired 2 retired drug reps. They learned about cardiac CT, and they went around to the referring physicians. Now the group is doing 10 to 12 coronary CTs a day. We need to develop some of that out-of-the-box thinking on how to excite the physicians who actually buy this to actually start doing these procedures, both for colon and cardiac imaging.

FISHMAN: So you agree that basically people are buying 64-slice but are too often living in a 4-slice world.

HAAS: Yes. As I said, we sell roughly 90% of our CT scanners right with cardiac imaging on them. We probably sell 40 to 50 with colon or perfusion imaging. But only 25% of customers use them. A lot of hospitals, once they buy a scanner, will keep that scanner for 5 to 7 years. So they assume that at some time within that 5 to 7 years, they will start doing that study. But how do we encourage them to actually start doing the imaging now to increase the procedures?

FISHMAN: How do you think it will become more automatic in these studies?

HAAS: I've been in cardiac CT for 7 years. What has changed is that scanners are being purchased to do these applications. But we still hear that workflow is a problem. You might have solved the workflow on the scanner, but you have to solve the workflow in reading.

Automation will allow the processing to be done as much by the computer as possible, so that radiologists can actually sit down and read, especially the normal cases, within 2 to 3 minutes. When it is a challenging case, it will take awhile to read and automation isn't going to work. Automator software works best when you get good data into the software.

If you have poor technologists or a site that isn't scanning well, the software automation will not work as well. So it is exciting, and you will see advances this year at RSNA. The software was developed for the ER. Thinking ahead, in how many years will CT in the ER become an all-night procedure? If we can automate it and send those images to a teleradiography site or a Web-based server, we can just have the images there. People don't want to sit for 15 minutes and do processing to get the answer. If we can have images available for them, they can read the case in a couple minutes.

FISHMAN: How long do you think it will be until we do CT in the ER routinely at night?

HAAS: I would have thought it would have started by now. We talked to ER physicians 3 or 4 years ago, and they were excited about it. But people are pushing back because they are afraid it is going to become like the head or chest CT and you will be doing 10 to 15 during the night. It will probably be a couple more years before it's a routine. But I believe it will be a routine exam in the near future.

WHITE: I have a comment about the hesitancy for radiologists to jump in for fear that we're not going to do these in 5 years. One advantage we have as radiologists is that there isn't a fear that we're going to steal the patient. There's a lot of perception that cardiologists will take the patient lock, stock, and barrel. That is never a threat with radiologists. So one thing that could probably be communicated to them is that in a sense, we are allies. We need to market directly to noncardiology groups. That is one thing I would encourage people to do.

HAAS: Right. When I speak, that's what I tell them. My goal is to excite the referring physician or to tell the radiologist to excite the referring physician. When referring physicians send their patients to the cardiologists, that patient may stay with the cardiologist. They are becoming mainstream physicians.

FISHMAN: I know that all of us in radiology have a hard time keeping up with radiology. Imagine what it is like for nonradiologists to try to figure out what radiology is doing. I don't know how they could even come close. Particularly outside the academic institutions, my experience has been that people's knowledge is what they knew when they finished their training. They still think that what we could do in 2000 is the same as what radiology can do now. They have no idea what we can actually do now. I gave a talk the other day and I had a feeling that the audience had those ideas. I just basically said, "I'm not going to give you data. I am going to give you 2 slides; here's the data. Now I am going to show you images and you can make up your own mind."

The imaging convinces people, but radiology does a very bad job of telling everybody else what we do. Part of the problem is that we don't often have the time or the right situations to do it. It's hard to reach those family docs and internists who are outside the academic centers. But I think that's critical for us.

HAAS: You also mentioned PAs? Where could you use a PA? This could be a great opportunity to get a PA into a physician center to talk to them. I was recently at a site looking at some of the equipment. They had a nurse who does a lot of their marketing to the referring physicians. In 1 year, they have built their practice up to roughly 10 patients a day. So the out-of-the-box thinking may be to hire a PA who can do some work for you inside. But they can also go out to talk to the community and to the referring physicians.

On a plane yesterday, I had 3 people sitting around me watching me do my presentation. They asked me what we were doing because they'd seen an ad somewhere or they'd heard about it. So the patients are very excited about this technique also. Getting the communities excited and reaching the referring physicians will just drive any one of these technologies.

To receive 6 CME credits, you must answer these test questions either online (follow the instructions on the inside front cover of this publication) or on the answer form on page 71 (fax or mail it to Anderson Publishing).

1. Which of the following is true, according to 2006 American Cancer Society statistics?
   A. When colon cancer is detected early, the survival rate is 75%.
   B. Only 25% of colon cancer is detected at an early stage.
   C. Lung cancer accounts for 50% of all cancer deaths.
   D. More women die of lung cancer than breast cancer.

2. Which of the following is an advantage [are advantages] of using computer-aided detection (CAD) and computer-aided reading (CAR) in lung CT?
   A. Physicians do not need to spend time visually inspecting images.
   B. CAD/CAR software can define nodules as solid, partially solid, or nonsolid.
   C. CAD/CAR software can identify potentially malignant lesions by detecting changes in volume over time and calculating doubling time.
   D. All of the above
   E. B and C

3. The spatial resolution of today's 64-slice scanners, when used for general CT, is approximately:
   A. 0.2 mm.
   B. 0.5. to 0.625 mm.
   C. 0.5 mm.
   D. 1 mm.

4. The step-and-shoot technique in cardiac CT is associated with which of the following?
   A. Prospective electrocardiographic (ECG) gating
   B. Data acquisition during both diastole and systole
   C. Automatic calculation of ejection fraction
   D. All of the above
   E. A and C

5. Which of the following is a [are] drawback[s] of retrospectively gated helical CT?
   A. It requires the use of a very low pitch in order to avoid gaps in anatomic coverage.
   B. Overlapping coverage increases the effective radiation dose.
   C. In patients with ectopy, data acquisition can occur during an undesirable cardiac phase.
   D. A and B
   E. All of the above

6. Which of the following is an improvement [are improvements] associated with prospectively gated axial CT?
   A. The scan delay is determined dynamically using several prior cardiac cycles.
   B. Increasing the duration of optimal tube current by 25 to 200 msec before and after each acquisition yields limited multiphasic datasets.
   C. Image quality is improved by elimination of undersampling due to cone beam geometry.
   D. B and C
   E. All of the above

7. Which of the following is [are] true of the comparison between retrospectively gated helical (RGH) CT and prospectively gated axial (PGA) CT?
   A. Reliability is significantly higher with PGA CT.
   B. Overall assessability of all coronary arteries is significantly better with PGA CT.
   C. Radiation dose is significantly lower with PGA CT.
   D. B and C
   E. All of the above are true.

8. Which of the following can be inferred from data in the BEIR VII report?
   A. A single 10-mSv effective dose confers approximately a 1-in-2,000 lifetime risk of developing a fatal cancer.
   B. The lifetime risk of fatal cancer associated with a single 25-mSv thallium examination is 1 in 400.
   C. The lifetime risk of fatal cancer associated with five 12-mSv CT scans conducted on a 64-slice scanner using RGH techniques and ECG dose modulation would be 1 in 333.
   D. A and B
   E. B and C

9. Approximately which proportion of patients who come to the emergency room with chest pain actually have acute coronary syndrome?
   A. 5%
   B. 10%
   C. 15%
   D. 20%

10. Which of the following is a limitation [are limitations] of the triple rule-out study?
    A. Suboptimal spatial resolution of the coronary arteries
    B. Streak artifact in the right coronary artery
    C. Increased radiation dose as compared with dedicated coronary CT angiography
    D. All of the above

11. Which of the following describes the contrast administration protocol used at the University of Maryland for the CT assessment of patients who come to the emergency department with chest pain?
    A. For a dedicated coronary CT angiogram: 80 mL of pure contrast material injected at 6 mL/sec, followed by 40 mL of contrast material mixed half-and-half with saline and injected at 5 mL/sec, followed by a 50-mL saline chaser injected at 5 mL/sec
    B. For a triple rule-out study: 100 mL of pure contrast material injected at 5 mL/sec, followed by a 50-mL saline chaser injected at 5 mL/sec
    C. For a triple rule-out study: 80 mL of pure contrast material injected at 6 mL/sec, followed by 40 mL of contrast material mixed half-and-half with saline and injected at 5 mL/sec, followed by a 50-mL saline chaser injected at 5 mL/sec
    D. For a dedicated coronary CT angiogram: 80 mL of contrast material injected at 5 mL/sec, followed by 50 mL of contrast material injected at 2 mL/sec, followed by a 50-mL saline chaser injected at 2 mL/sec

12. Which of the following is a challenge [are challenges] in implementing CT in the evaluation of patients who come to the emergency department (ED) with chest pain?
    A. Adding CT to the standard work-up markedly increases the cost of the ED visit..
    B. CT scanners are seldom sited near the ED.
    C. Only radiologists can read the studies.
    D. Triple rule-out studies may strain healthcare resources by increasing scan volumes.
    E. All of the above

13. Which of the following is [are] true of colorectal carcinoma in the United States?
    A. It is the number-2 cause of death in the United States.
    B. Approximately 50 million people in the United States are at risk for colon cancer and eligible for screening.
    C. The target of screening is a malignant lesion.
    D. All of the above

14. Which of the following does NOT characterize typical patient preparation for CT colonography?
    A. The administration of a cathartic agent
    B. The administration of a fecal tagging agent
    C. The placement of an intravenous line
    D. Gas insufflation by a computer- and pressure-controlled automated carbon dioxide insufflator.

15. Which of the following describe[s] an optimal CT colonography scan?
    A. It is performed on a multidetector scanner with a rotation time of ≤500 msec.
    B. It encompasses the entire abdomen and pelvis.
    C. The radiation dose is typically <3 mSv.
    D. All of the above

16. Which of the following is NOT a characteristic of CT colonography performed using optimal techniques?
    A. A specificity of >90%
    B. Reports of at least some discomfort in 30% of patients
    C. A complication rate of 0.4%
    D. None of the above is characteristic of CT colonography.

17. Which of the following is NOT characteristic of capsule endoscopy?
    A. The capsule takes continuous photographic images of the small bowel lumen with a 360˚ field of view.
    B. Capsule endoscopy can miss lesions at the site of focal disease.
    C. The image set can be tedious to review and interpret.
    D. Capsule endoscopy is contraindicated in patients with small bowel stricture or obstruction.

18. Which of the following is NOT an advantage of using water as an oral contrast agent in CT enterography?
    A. Water is a neutral contrast agent.
    B. It is well tolerated by patients.
    C. It is effective for distending the stomach and proximal and distal small bowel.
    D. It is inexpensive.

19. Which of the following describes the oral contrast administration protocol used at the University of Pittsburgh Medical Center for CT enterography of the small bowel?
    A. 1,350 mL of water divided into 450-mL portions consumed at 15-minute intervals, with the last 150 to 200 mL consumed just before scanning
    B. 1,350 mL of VoLumen, divided into 450-mL portions consumed at 15-minute intervals, with the last 150 to 200 mL consumed just before scanning
    C. 950 mL of VoLumen, divided into 450-mL portions consumed at 10-minute intervals, with the last 150 to 200 mL consumed just before scanning
    D. None of the above

20. Which of the following would commonly be found on CT enterography in a patient with sprue?
    A. Jejunal fold hypertrophy
    B. Prolapse of one section of the bowel into another
    C. Ileal fold atrophy
    D. All of the above

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5. ○A ○B ○C ○D ○E	**10.** ○A ○B ○C ○D	**15.** ○A ○B ○C ○D	**20.** ○A ○B ○C ○D

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