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FOCUS ON *CARDIOVASCULAR CT*

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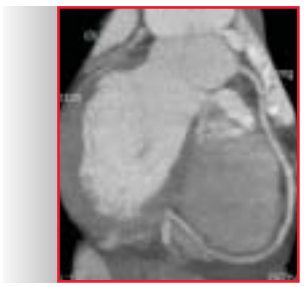
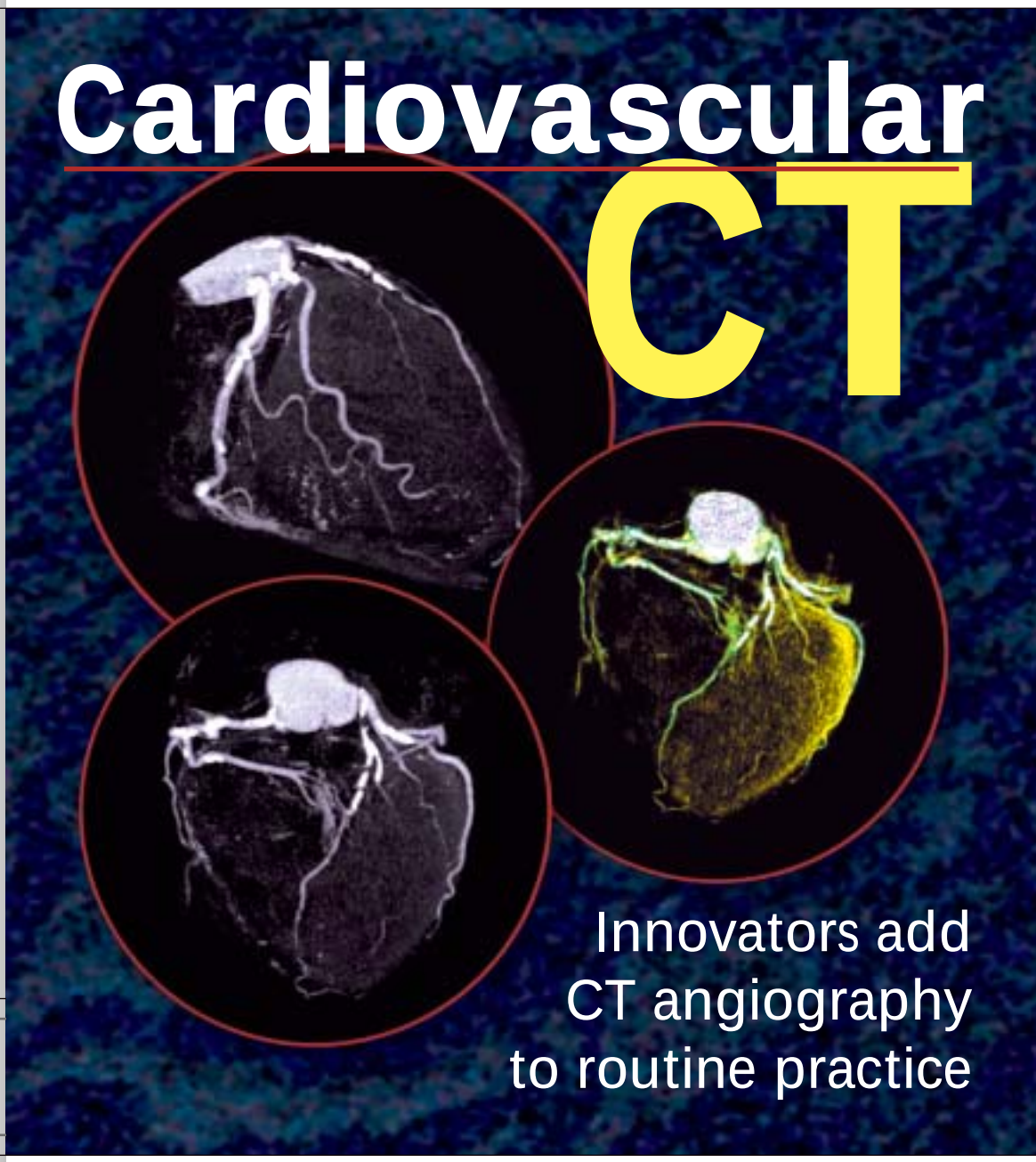


SCREENING
CT leads imaging field in plaque assessment

COLLABORATION
Specialists discover common ground in cardiovascular CT

TRAUMA
MSCT tackles acute chest pain in emergency room

PAYMENT
CT angiographers predict widespread reimbursement



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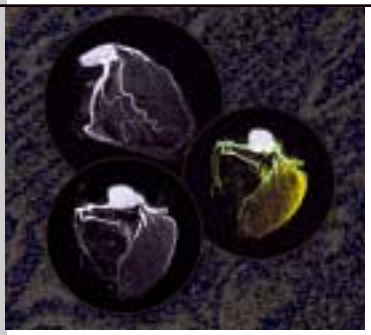

Cardiovascular CT

Innovators add CT angiography to routine practice

CT innovators charge ahead in heart and vessels

The talk at the 2004 RSNA meeting was all about CT. Even with only the smallest handful of papers presented on 64-slice experience, radiologists discussed the latest generation of scanner as the new must-have equipment.

While still largely unproven, the potential is great, and the focus is on cardiovascular applications. The ability to characterize and quantify both calcified and soft plaques is hailed as a step up from older calcium scoring studies, even if the exact course of treatment for a given plaque burden is still uncertain. Studies of the heart's vessels are competitive with traditional angiography and ultrasound, though the need for further research remains.

In this supplement, *Diagnostic Imaging* looks at how CT technology is shaping cardiovascular imaging and practice: innovators who have been successful at obtaining reimbursement for studies, researchers who are testing the limits of plaque analysis, and teams of cardiologists and radiologists who are working together to ensure that each contributes expertise to cardiac evaluation and treatment built on these evolving techniques.

—Jane Lowers
Special Projects Editor

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BY SARAH JERSILD

CT angiographers predict widespread reimbursement

While 16-slice technology makes CTA feasible, 64-slice scanners on horizon could make procedure widespread practice

It's not a question of if, but of when. Both academic and private-practice radiologists who perform cardiac CT angiography predict that reimbursement for the procedure will become widespread within a year.

"It's such a great exam for patients. It's got such great momentum that nothing can stop it," said Dr. David Dowe, COO of Atlantic Medical Imaging in Galloway, NJ.

Dowe can afford to be enthusiastic about the technology. His regional Medicare carrier began reimbursing cardiac CTA in June 2004, and Dowe said he has experienced no rejection from private insurance carriers, despite the fact that no specific CPT codes for cardiac CTA exist. He bills for the procedure in two ways: as a chest CT and a chest CT with contrast. The latter examination allows radiologists to investigate other possible causes of chest pain beyond the heart, such as a pulmonary embolism or aortic distention.

"There's a list of other things that could be causing chest pain," said Dr. David Levin, emeritus radiology chair at Thomas Jefferson University. "There's good justification for saying we're going to not only do a coronary CT angiogram, but look at the rest of the chest for other possible abnormalities that could cause those symptoms."

Some practitioners say those repurposed codes are not enough, however.

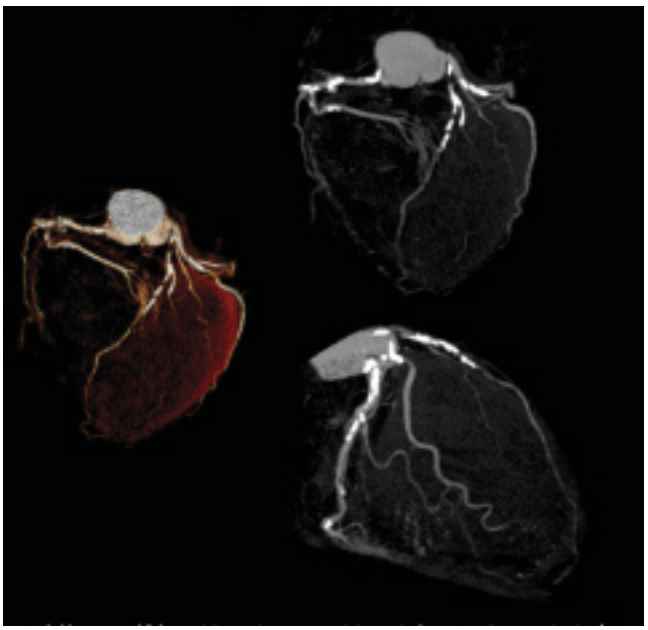
"It entails a lot more work than standard CTA of the chest for the thoracic aorta or pulmonary vasculature," said Dr. Brent Greenberg of Greenberg Radiology in Highland Park, IL. "There's a lot more work on the workstation and it needs to be ECG-gated."

Greenberg currently offers cardiac CTA on a self-pay basis. Until the procedure gets a CPT code of its own, he doesn't anticipate that insurers in his area will reimburse for it.

Ideally, cardiac CTA should have three CPT codes, said Dr. Edward Shapiro, a professor of medicine at Johns Hopkins University: one for assessment of coronary anatomy, including stenosis and extent of nonstenotic coronary disease; a second for 3D analysis of global and regional ventricular function; and a third code for a radiologist screen for noncardiac disease.

Until the literature wholeheartedly endorses cardiac CTA, radiologists cannot expect it to be widely reimbursed, said Dr. John A. Patti, chair of the American College of Radiology Commission on Economics. He cited a literature review by Dr. U. Joseph Schoepf et al in the July 2004 issue of *Radiology* that labeled the technology "promising enough to warrant pursuit of this application." The authors concluded, however, that "sensitivity is still not high enough for routine diagnostic needs."

That lack of unanimous endorsement from aca-



16-second CT scan can reveal calcifications consistent with advanced coronary artery disease. (From Charité Hospital, Berlin)

Ms. Jersild is a freelance writer in Chicago.

demic centers is the main hindrance to a wider adoption of CTA. The technology must be reproducible in a given patient, in a group of patients, and across multiple centers, said Dr. William T. Thorwarth Jr., immediate past president of the ACR.

"Just because something can be done in an academic research institution by the initial investigators does not mean it is immediately ready for coverage and widespread use," he said. "There has to be a reasonable consensus on the imaging protocols, equipment requirements, technologist and doctor expertise."

It remains to be seen whether cardiac CTA will be given a unique code or will continue to fit under an existing code. Regardless of whether a new code is adopted, insurers are not leaping to pay for new technologies, according to Patti.

"Getting adequate reimbursement for new technology is a huge issue for payers now. They realize it's very expensive and they want to be sure it's doing the patient some good, that it's not just another study that gets piled on top of all the other studies. They're being rigorous in examining the literature to make sure that before they do pay for something, it's going to be worthwhile," he said.

Supporters say cardiac CTA is well on its way to meeting those criteria. Its ability to eliminate cardiac catheterization for many patients will win insurers over, Levin said.

One of the main advantages of the technology is that it can quickly and easily eliminate coronary diseases as a source of chest pain.

"The most common indication for doing a coronary CTA is a patient with chest pain who has a positive stress test," Dowe said. "Ninety percent of the time, I give them a negative or near-negative coronary CTA. I don't think anyone should go to the cath lab without a coronary CTA if you have a center that does 16-slice coronary CTA and does it well."

Eighty-four percent of the patients he sees for cardiac CTA are either normal or have some plaque with no stenosis, Dowe said. Of the remaining patients, 13% need additional stress tests to correlate with the cardiac CTA, and 3% go directly to catheterization for treatment.

About 40% of cardiac catheterizations return a negative result, he said. Cardiac CT could eliminate these unnecessary catheterizations, and that is becoming a key factor drawing researchers to the procedure.

"Instead of subjecting patients with minimal symptoms, minimal chest pain, or atypical chest pain to an invasive procedure that's expensive, involves multiple individuals having to get together, and is very time-consuming, you'll be able to do this relatively quickly with minimal morbidity and essentially no mortality," said Dr. Charles White, director of thoracic imaging at the University of Maryland.

In addition, cardiac CTA provides a fuller picture of the coronary arteries than coronary angiography during catheterization can offer, according to Levin. Instead of showing just the lumen, cardiac CTA gives radiologists a picture of the walls of the vessel, allowing them to see plaques in the walls that don't encroach on the lumen.

Another advantage that cardiac CTA advocates tout is the technology's lower cost compared with other methods. Dowe said he is reimbursed about $1000 for a chest CTA and chest CTA with contrast. He cited an article in *The New York Times* that estimated the cost of a cardiac catheterization, including hospital and facility fees, to be as high as $18,000.

CT angiography reveals plaque (arrow) in 22-year old asymptomatic woman with cholesterol of 220 and a significant family history of heart disease. (Provided by D. Dowe)

64-SLICE VERSUS 16-SLICE

Despite the promise of the technology, even its most passionate adherents admit that cardiac CTA is not quite ready to replace catheterization. With 16-slice equipment, the necessary breath-hold of 20 to 25 seconds and the contrast load can be too arduous for some patients. In addition, patients often must be beta blocked, the heartbeat has to be sufficiently slow, and the bolus injection must be precisely timed.

The main criterion is the sensitivity of the scanner, which is related to signal-to-noise ratio. Vendors are using a number of strategies, including increasing the milliamperage to boost signal and employing various algorithms to reduce noise.

Cardiac CTA cannot be reliably performed with less than a 16-slice scanner, and 16 is considered the barest minimum. Payers that do reimburse for cardiac CTA mandate these high-slice machines. Medicare of New Jersey, which reimburses for the procedure, requires at least a 16-slice machine and a submillimeter cut, Dowe said.

"They're not going to let just anybody with a box do it," he said.

The wider availability of higher slice machines is seen as the driving force behind the acceptance and eventual reimbursement of cardiac CTA. While 16-slice scanners are making cardiac CTA more accessible, researchers say the advent of 64-slice scanners will make the procedure practical on many levels within the near future.

The improvement will not be in image quality, Dowe said, but in the speed with which the procedure can be accomplished. With a 16-slice scanner, the scans take 15 to 18 seconds. With a 64-slice machine, they take about five seconds.

"A 64-slice scan will make coronary CTA possible in just about everyone, using only four to five beats. At that speed, you could scan a hamster," he said.

Even the most enthusiastic backer of the technology agrees that cardiac CTA is not a procedure to be taken lightly. White cautions that a patient who has a very high risk of significant coronary artery disease would probably be better served by a trip to the cath lab, where therapy can be administered immediately through the catheter. Experts warn that cardiac CTA should not be performed in patients with no risk factors and no symptoms.

"There is a justifiable fear that this technology could be overused," Shapiro said. "There's no evidence at the present time that it's effective or cost-effective in clarifying risk for asymptomatic patients. This is not something that's ready to be a screening test; there's too much radiation and contrast given to justify the approach."

WORKING TOGETHER

As the technology is rising to the challenge of cardiac CTA, experts warn that education of both radiologists and referring physicians may be the next stumbling block.

"I don't think it's sunk in what the power of the technology is," White said. "The internist, cardiologist, family medical physician, and surgeon should be thinking of this as the study to order under appropriate circumstances."

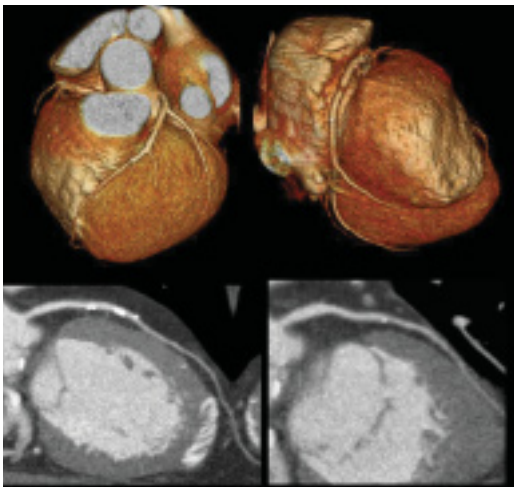
This is one instance where cardiologists and radiologists may accomplish more by working together.

"Both the ACR and the American College of Cardiology are very aware of the issue of reimbursement for cardiac CTA," Patti said. "I'm sure they're going to work together to reach a solution once the technology becomes more widespread and accepted and good studies prove the efficacy. I think it's going to be a collaborative effort to make sure this is properly coded and reimbursed."

Even vehement turf warriors such as Levin believe that cardiac CTA will be most effective if both specialties cooperate. Both Levin's program at Jefferson and White's at the University of Maryland emphasize collaboration between the specialties. Greenberg expects cardiac CTA to increase interventional cardiac catheterizations performed by cardiologists in patients who might otherwise have been missed while simultaneously eliminating diagnostic catheterizations for patients without disease.

"(Cardiologists and radiologists) need to play in the sandbox together," Greenberg said. "If cardiologists view this not as a threat but as something likely to produce more interventional catheter studies and procedures, they'll see it won't be taking money out of their pocket."

Cardiologists hoping to adopt cardiac CTA on their own may face serious reimbursement barriers, Dowe said. The American Heart Association recently issued a position paper stating that cardiologists who perform the procedure should have a radiologist's backup.



64-slice scanner acquired images of mixed coronary plaque at 0.5-mm resolution in nine seconds. Soft and hard plaque are present in left anterior descending artery. (Provided by Toshiba)

That position is an attempt to save the healthcare system, he said.

"We're finding that private payers are beginning to not credential nonradiologists for high-tech imaging like CT, MR, and PET because they know it's going to explode and be massively overutilized," Dowe said. "If used correctly, cardiac CTA could save the healthcare system a ton of money. If the cardiologists refer it in addition to a stress test and catheterization, it'll be the straw that broke the camel's back."

Even without reimbursement, doctors who perform cardiac CTA expect its star to rise.

"People won't pay for things that don't have value," Greenberg said. "No one is reimbursed for calcium scoring, but it still survives because calcium scoring has a definite value. Just like the calcium scoring, cardiac CTA has that value." ■

BY DEBORAH R. DAKINS

CT leads imaging field in plaque assessment

Multislice tool bests competitors for screening, but its ultimate role in predicting cardiac risk remains unclear

CT is moving beyond detection and quantification of coronary artery calcium to grading of coronary stenoses, identifying not only vulnerable plaques but, more important, vulnerable patients. Yet its ultimate role in predicting risk of cardiac events remains unclear.

There's no question that coronary CT angiography will cut a swath through the estimated 3.5 million conventional coronary angiography exams performed annually. Only about one-third of these invasive, expensive procedures are undertaken as part of an intervention, while the remainder are performed to verify the presence and determine the degree of coronary artery disease.

A growing number of cardiac imagers agree that CT does a better job. Unlike coronary angiography, which assesses the lumen, CT exploits its cross-sectional capability to evaluate the vessel wall. It is here that early-stage stenosis, considered the culprit behind acute coronary syndromes, hides. Merely documenting lumen dimensions with conventional angiography fails to provide a complete portrait of plaque accumulation (Radiology 2004;232:7-17).

"Acute coronary events are triggered by rupture of rupture-prone plaques in the coronary arteries," said Dr. U. Joseph Schoepf, an associate professor of radiology and director of CT research and development at the Medical University of South Carolina in Charleston. "The importance of detecting and characterizing plaque is to prospectively identify patients who are prone to plaque rupture. It would be an incredible achievement to be able to actually prevent these events."

While radiologists have known for years that MSCT's greatest application is in the heart, only recently has the added value of the latest generation of multislice machines been documented in the peer-reviewed journals. Several studies presented at major meetings in the past year offered comparisons among CT and coronary angiography, intravascular ultrasound, and MR. They found that contrast-enhanced 16-slice CT accurately, and noninvasively, detects calcified and noncalcified coronary plaques.

A consensus is emerging that each modality has a role to play, depending on whether the goal is prevention, intervention, or therapy management.

PREVENTIVE ROLE

Prior to the introduction of 16-slice CT and ECG-gated coronary CT angiographic techniques, electron-beam CT devices were lauded for their ability to score coronary calcification. Many sites now performing coronary CTA to evaluate patients for atherosclerosis have discontinued calcium scoring in favor of the new, more comprehensive study.

Coronary calcium scoring leaves too much

CTA provides more comprehensive information about coronary plaque than EBCT calcium scoring or conventional angiography. (Provided by Dr. Brent Greenberg, Greenberg Radiology Imaging, Highland Park, IL)

Ms. Dakins is feature editor of Diagnostic Imaging.

information on the table, according to Dr. David Dowe, medical director of Atlantic Imaging in Galloway, NJ.

"Coronary CTA is so much more than calcium scores," he said. "It shows the hard plaque, the soft plaque, and blockages. But calcium scoring has a big head of steam, and people confuse it with CTA, which is the reason I don't even offer calcium scoring."

CTA's negative predictive value is stellar, but its positive predictive value may need a little work. In a study presented at the 2004 American Heart Association meeting in New Orleans, Dr. Stephan Achenbach, an assistant professor of radiology at the University of Erlangen in Germany, used 16-slice CT to evaluate coronary artery segments in 50 patients scheduled for conventional angiography.

Sixty-five stenoses in 664 segments were present; in 5% of these segments, CT could not evaluate due to motion artifact or calcification. In the remaining segments, CT demonstrated 93% sensitivity, 95% specificity, negative predictive value of 99%, and positive predictive value of 68%.

Two additional studies based on 16-slice CT report 79% and 80% positive predictive values in evaluating stenoses of 50% or less (Circulation 2002;106[16]:2051-2054; Circulation 2003;107[5]:664-666).

Those results mesh with the recommendations of a research group headed by Dr. Axel Kuettner, a radiologist with Eberhard-Karls University in Tuebingen, Germany. Kuettner's study, published in the *Journal of the American College of Cardiology*, demonstrated CTA sensitivity and specificity for detecting coronary stenoses in the high 90% range. But it noted that 16-slice CT is at its best in evaluating low to moderate amounts of coronary artery calcium (JACC 2004;44[6]:1230-1237).

That's an opinion shared by several radiologists now routinely using coronary CTA for evaluating asymptomatic patients—the group expected to benefit most from the technique.

"Patients with advanced atherosclerotic disease, including heavily calcified vessels, have vessels that look like coral because of all the calcium," said Dr. Stephen Koch, medical director of Imaging Heart, a private practice in New York City. "This can lead to the blooming artifact phenomenon, where calcium looks bigger than it actually is in the anatomy."

The advent of 64-slice CT is expected to limit the artifact with thinner slices and improved resolution, but Koch considers asymptomatic patients the most appropriate for evaluation with coronary CTA. Dr. Melvin Clouse, vice chair of radiology and director of radiology research at Beth Israel Deaconess Medical Center in Boston, agrees.

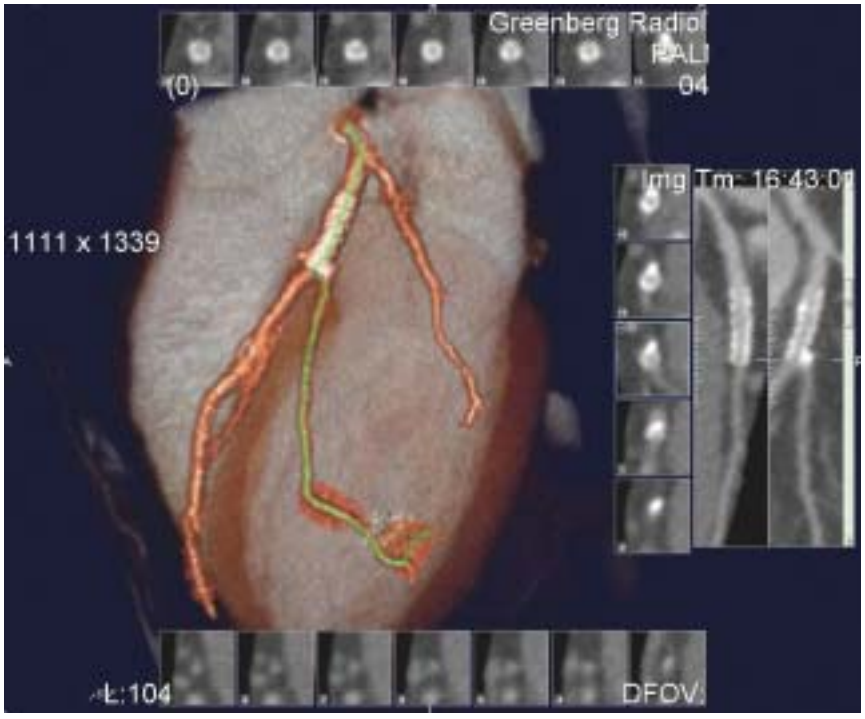
"Coronary CTA will obviate the need for a lot of cardiac catheterizations, but I think the payoff is going to be in prevention," he said.

COMPARATIVE MODALITIES

Intravascular ultrasound has been called the gold standard for detecting soft plaque, which is the type most likely to rupture. But its invasiveness makes it an inappropriate tool for asymptomatic patient evaluation.

Because of IVUS, however, radiologists have a better understanding of vulnerable plaque characteristics: large lipid pool, thin fibrous cap, and an intense inflammatory response.

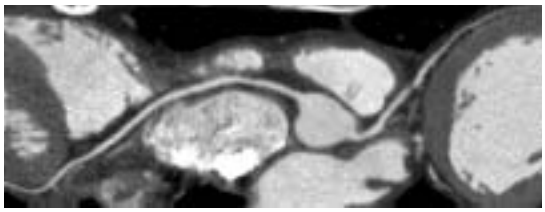
"The ability to detect plaque vulnerability and also assess plaque burden is important," said Dr. Paul Schoenhagen, a staff physician in the departments of radiology and cardiovascular medicine at the Cleveland Clinic. "We know from IVUS that these lesions develop early and progress over time. By the time a patient shows up in the cath lab with a coronary event, often there are large amounts of plaque in other arteries that might look normal on an



CT excels at differentiating between calcified and noncalcified plaque. (Provided by B. Greenberg)

angiogram. We can now quantify that plaque burden with IVUS."

Schoenhagen and colleagues scored CT against IVUS in a 2003 study, finding that the tomographic technique can accurately identify mildly stenotic coronary atherosclerosis and also provide assessment of morphology and arterial remodeling.



Curved planar reformatting of right coronary artery and left anterior descending artery shows soft plaque. (From Johns Hopkins University)

The team stopped short of a full endorsement, however, noting that CT's ability to identify calcified and noncalcified plaque components is not sufficient to predict clinical events (Coronary Artery Disease 2003;14(6):459-462).

If the goal is simply to identify the best noninvasive screening tool, IVUS is out of the running. That leaves CT and MR, both of which have advantages. CT has higher resolution and can image the coronary arteries better than MR, Schoenhagen said. But MR has better tissue characterization, as has been shown in the carotid arteries.

Factor in 64-detector functionality to CT's existing speed and spatial resolution, and it becomes possible to investigate the entire coronary artery tree.

"With 64-slice CT, using an ECG-gated scan, we are in the range where it takes about 10 seconds to scan the entire heart," Schoepf said.

CT's weakness lies in its limited contrast resolution for differentiating types of tissue, which affects its ability to characterize plaque. It's an inherent limitation, one that even the improved spatial resolution of 64-slice CT will only partly address.

"CT does a very good job of differentiating between calcified and noncalcified lesions," he said. "But it cannot reliably differentiate between lipid-rich lesions and fibrous tissue within a coronary artery lesion. That's a problem."

By reducing volume averaging artifacts, it may be possible to improve measurement of different tissue attenuations, according to Schoepf.

FORMING A STRATEGY

Rather than pitting one modality against another for plaque detection, Schoepf favors a coordinated approach.

"With MR, CT, and IVUS, you are talking about three completely different entities with their own sets of advantages and disadvantages," he said. "We should be thinking of strategies for using them in a complementary way."

IVUS is best for evaluating specific lesions identified by invasive catheter angiography or by noninvasive tests. Use of MR as a noninvasive screening tool means accepting a host of trade-offs: speed for spatial resolution, or vice versa. Yet MR's superior contrast resolution makes it an important tool for evaluating plaque composition, Schoepf said.

"We can use CT for detecting lesions and then look into different modalities, such as MR, to differentiate between tissue types and look at lesion composition," he said. "So a noninvasive approach would begin with CT for detection and continue to MR for lesion differentiation. If the lesion is significant enough to warrant therapy, you can perform IVUS prior to stenting the lesions or performing another intervention."

Schoenhagen agrees that a multipronged approach that is guided by clinical indications is appropriate. The method should be different, however, depending on whether the goal is to prevent disease or to determine an appropriate intervention strategy for specific lesion types, he added.

"Although there are groups working on CT and MR, CT is clearly leading the field," he said. "Most people do not anticipate that MR will contribute significantly in the next few years, while CT is expected to do so."

Combining the capabilities of 32-slice CT with a stress test (most likely pharmacologically induced) might result in a tool that provides all physicians need to know about a patient's coronary artery disease.

Coronary CTA may also be able to detect relevant coronary artery obstructions in addition to necrosis and hibernation, according to Dr. Myron Weisfeldt, chair of the department of medicine at Johns Hopkins University. And it may offer quantitative measures of flow in the arteries and heart muscle.

Curved planar reformatting shows both calcified and noncalcified plaque in left anterior descending artery. (Provided by Toshiba)

THERAPY MANAGEMENT

CT may also play a role in monitoring response to statin therapy, particularly in light of the potential risks that lipid-shrinking drugs pose for some patients (Radiology 2004;232:18-37).

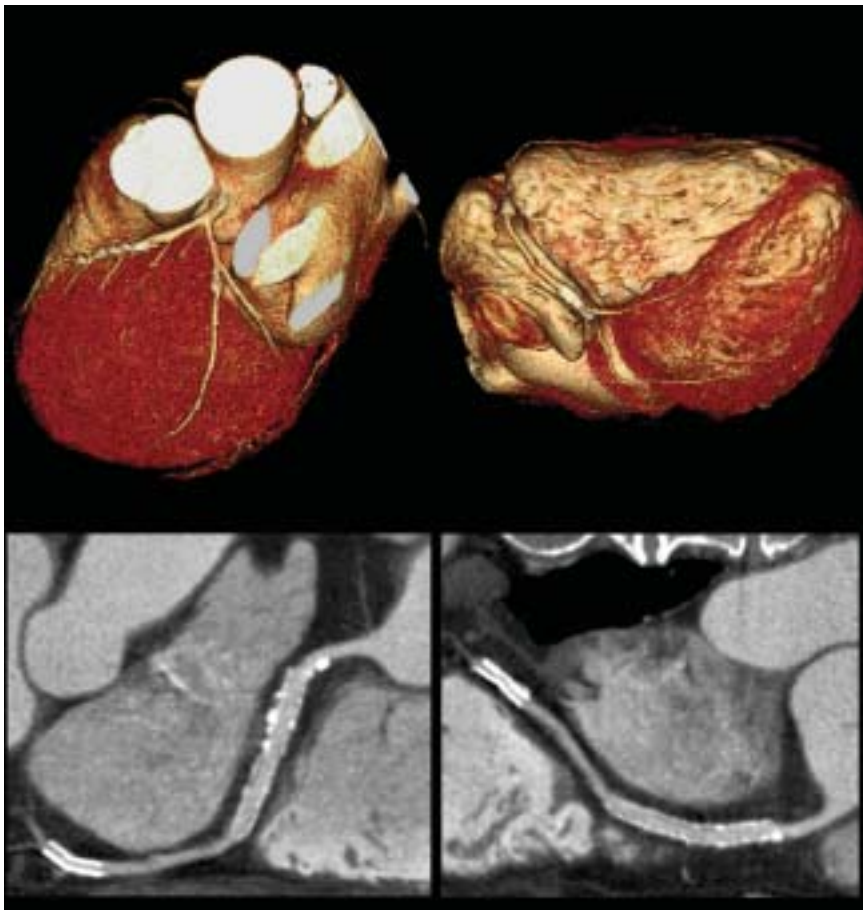
"We want to make sure that patients who receive statin therapy are actually responding to the treatment, so that we're neither wasting money nor increasing the risk of side effects in patients who do not benefit from it," Schoepf said. "In theory, CT is a very elegant, noninvasive way of doing that."

One study, based on coronary calcium scores acquired with EBCT to evaluate response to statin therapy, offered promising results. Researchers were able to track stability and, in some cases, regression of plaque burden (NEJM 1998; 329(27):1972-1978). But reproducibility of such results with EBCT is a problem, Schoepf said.

Variability between two tests even only five minutes apart can range as high as 30%. Use of retrospective ECG-gating combined with the thinner sections of 16-slice CT can reduce such variability and provide a more reliable measurement of calcified plaque burden, Schoepf said.

Calcified plaque is only the tip of the iceberg, however. CTA is emerging as a tool to evaluate the entire plaque burden: fibrous tissue, lipid tissue, and the pathophysiology of vascular remodeling that occurs in noncalcified regions of the vessels. It's this tissue that responds more readily to statin therapy.

"What we hope is that by looking at the noncalcified disease component with CTA, we'll get a faster and more reliable response rate assessment," Schoepf said.



Curved planar reformatting and 3D views confirm ulcerated plaque. (From Johns Hopkins University)

VULNERABLE PATIENTS

While CT may indeed prove important as an endpoint application to evaluate treatment response, its use as a noninvasive screening tool is stirring up much more interest. Its promise has opened the door to a new approach in patient workup, Clouse said.

"We can see amazing things with 16-slice CT," he said. "It's important that we continue to address early diagnosis of atherosclerosis by looking for soft plaque. We spend more than one-third of our trillion-dollar healthcare economy treating endstage cardiovascular disease. It's a figure that boggles the mind."

Research continues on identifying and quantifying plaque, as well as documenting arterial remodeling, plaque progression, and regression. But the discovery of one magic bullet is unlikely.

"It's a misconception that any imaging test can look at the coronary tree of a patient, see a lesion that looks rupture-prone, and predict that this lesion is going to rupture," Schoepf said. "It's part of the hype around this modality."

To know CT's ultimate role in plaque characterization is to understand the complexity of atherosclerotic disease. Patients with noncalcified plaques in coronary arteries are also likely to harbor disease in the carotids or ascending aorta.

"Atherosclerosis happens everywhere there is a vessel in the body," he said. "Simply looking for vulnerable plaque isn't leading us anywhere. Better to identify vulnerable patients who have lesions prone to rupture, using all of the tools we have, and determine who is at risk and who may benefit from specific therapies." ■

BY KAREN SANDRICK

MSCT tackles acute chest pain in emergency room

Emerging protocols and tightened postprocessing target cardiac and noncardiac origins in one scan

As a one-stop scanning tool for everything from abdominal trauma to chest pain, CT is fast becoming an emergency room's best friend. Medical centers save trauma treatment costs by taking less staff to support a patient until a diagnosis is made, and they improve emergency care by cutting the time patients spend being imaged before being stabilized and acutely managed.

CT provides exceptional detail. Tiny, scattered opacities that might have suggested pneumonia on older scanners have been supplanted by "tree and bud" signs throughout the lungs that show the true extent of the inflammatory disease process.

CT is fast replacing some standard emergency imaging procedures. Because a chest CT scan can rule out an aortic injury in eight seconds, it leads to a diagnosis and triage decision far more quickly and less invasively than a two-hour angiographic exam. CT is less cumbersome than arteriography or V / Q scans, which often require transporting patients to the catheterization lab or the nuclear medicine department and waiting for the vascular or imaging team to assemble.

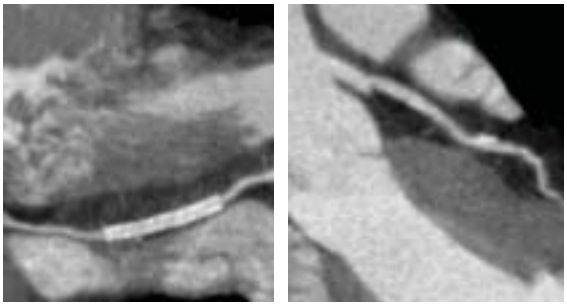
The introduction of 64-slice scanners may revolutionize vascular and cardiac imaging in the emergency department. Dr. Theodore Dubinsky, an assistant professor of radiology at the University of Washington, Seattle, is convinced that radiologists can see myocardial infarcts on current CT scans. In the future, when scans are gated, CT could be used to identify or rule out a coronary cause for acute chest pain. Multislice CT will open the door to imaging the heart in diastole with high resolution of the muscle and coronary vessels. Common acute conditions of the chest, such as pulmonary embolism and aortic dissection, can be checked in one scan.

"The CT study for acute chest pain patients is going to be a fundamental change in how we manage these patients," Dubinsky said. "As it is now, clinicians have to pick: Do they think a patient has an aortic dissection, a pulmonary embolism, or a myocardial infarction? If they suspect an MI, they put an electrocardiogram on the patient and draw bloods, but ECGs are only 60% to 65% sensitive for MI. I have a feeling CT is going to be better. We've seen MIs in patients who have negative ECGs and normal serologies."

CURRENT PRACTICE

Cardiovascular CT is routine for evaluating both nontraumatic and traumatic vascular emergencies, including abdominal aortic aneurysm, aortic dissection, inflammatory disease of the blood vessels, thromboembolism, and aortic injury. Today's scanners can scour the lungs for pulmonary emboli and move right down the body to the pelvis and legs to search for venous thromboemboli in the pelvic veins or extremities. Sixteen-slice machines can traverse the body from the top of the head to the femur in two minutes, acquire 500 or so slices, and produce 3D models of the blood vessels in the head and neck, chest, and abdomen. The machines can clearly and accurately evaluate up to 90% of all aortic traumas, said Dr. Robert Novelline, a professor of radiology and director of emergency radiology at Massachusetts General Hospital.

Evaluation of chest pain by directly imaging the coronary arteries is just beginning. In one case



Curved planar reformatting shows stent in right circumflex artery and soft and calcified plaque. (From Fujita Health University)

Ms. Sandrick is a contributing editor for Diagnostic Imaging.

report, Dubinsky and his colleagues at Harborview Medical Center wrote that MSCT revealed a distinct area of hypoperfusion in the lateral ventricular myocardial wall of a 55-year-old man who had an indeterminate ECG after being brought to the emergency department because of left-side chest pain.

Even older scanners can play a role. In a study of 28 patients who had been admitted to an emergency department in Japan because of chest pain consistent with acute myocardial ischemia but nondiagnostic ECG changes and normal serum troponin T levels, four-slice CT detected all 19 cases of angiography-confirmed acute coronary syndrome. Scans performed within six hours of the onset of chest pain correctly identified 50% or greater stenosis in major coronary arteries in the presence of noncalcified plaque in all 19 patients. It also detected nontransmural perfusion defects in four patients and produced only one false-positive result. Authors of the study, which was presented at the 2004 RSNA meeting, concluded that four-slice CT was 100% sensitive and 89% specific for identifying and triaging patients with acute coronary syndrome in the emergency department.

On the way to developing a one-stop MSCT protocol for determining cardiac, pulmonary, and musculoskeletal causes of acute chest pain, Dr. Charles White is working on what he calls a hybrid plan for assessing patients with intermediate levels of chest pain. These patients experience something between the two extremes of chest pain—severe, clearly heart-related pain and troubling but minor or musculoskeletal discomfort.

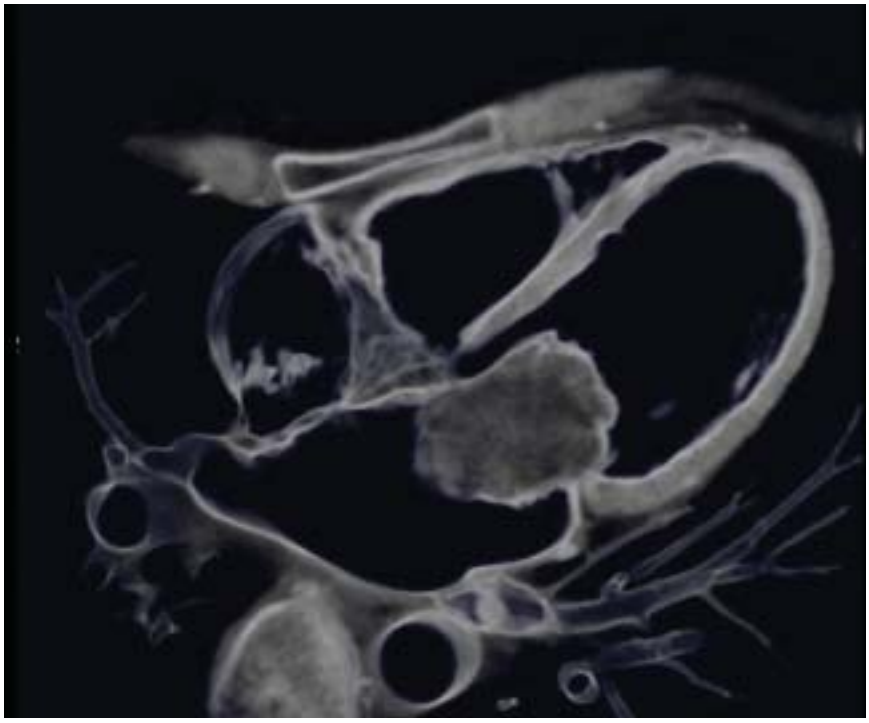
The protocol is a compromise between scanning for pulmonary embolism and conducting a specific study of the coronary arteries. A coronary artery study is best achieved with a small field-of-view that is honed down to the heart, with volume coverage extending from the top of the heart to the bottom and cardiac gating, according to White, director of thoracic imaging at the University of Maryland, Baltimore. This approach does not include much of the lungs, however. A pulmonary embolism study uses higher pitch to traverse the chest more quickly and is not gated.

White's compromise is to perform a gated study that begins at the bottom of the cardiac cavity so scanning will cover the entire heart during a breath-hold. Patients then can begin to breathe and exhale slowly while scanning covers the top of the lungs, where images are less vulnerable to motion. He uses a field-of-view large enough to include the periphery of the lungs and reconstructs images only of the heart.

Although scan acquisition according to this protocol is fairly long, on the order of 35 seconds, it is feasible with a 16-slice scanner, White said. A study reported at the 2004 RSNA meeting showed that even though the protocol does not fully optimize the coronary arteries, it produces a good enough view of the blood vessels to rule out significant vascular disease. In the study, which included 69 clinically stable patients, CT identified a significant cause of chest pain in 13 (19%) patients, 10 cardiac and three noncardiac in nature. The 16-slice technique directly visualized the coronary arteries and had a high specificity and negative predictive value for atypical chest pain. CT had a sensitivity of 87%, specificity of 96%, positive predictive value of 87%, and negative predictive value of 96%.

"This approach holds out the prospect that if the CT is negative, the suspicion of cardiac chest pain would be low, and workup could stop instead of waiting the extra time and doing extra tests. It could have a huge impact," White said.

The proportion of myocardial infarctions that are "missed" in an emergency department ranges from



16-slice CT study, reformatted to a transparent volume rendering, shows heart's four chambers with an atrial mass protruding through mitral valve. (From Johns Hopkins University)

2% to 8%, and the death rate for these patients after hospital discharge is about 25%, said Dr. Mel Clouse, head of interventional radiology at Beth Israel Medical Center in Boston. These patients most likely come in with ruptured plaque and a small amount of clot in the coronary vasculature that either causes chest symptoms or blocks blood flow downstream but does not produce a sufficient degree of ischemia to elevate cardiac enzymes. The patients therefore lie around in the emergency department for several hours, receive hydration and pain medication, and leave when they seem better, only to suffer MI when a coronary vessel later completely clots off.

"Rapid scanners have made it possible to get images of the pulmonary arteries, aorta, and coronaries. There's no question where the technology is going and where it will find one of its important uses—imaging individuals who have chest pain symptoms at the outset. But it will take a little doing to get the protocol worked out so that your timing and the scanner don't produce artifacts," Clouse said.

CT has become a routine assessment tool for chest pain of multiple origins, including aortic aneuryms, and for follow-up evaluation after treatment. (Provided by Toshiba)

Clouse is still tinkering with the specifics of his protocol. He has tried setting Hounsfield units for the main pulmonary artery at 180, moving to just above the aortic arch, and gating the study all the way down. This takes about 24 seconds and clearly demarcates the vasculature but fails to anatomically detail lung parenchyma. He is experimenting with other alternatives, such as beginning at the top of the chest and performing nongated imaging through the chest, then moving to the coronary root and switching to gated imaging through the heart. He considers slice thickness critical.

"To the uninitiated eye, the difference between a 0.5- and 1-mm slice is not all that great. But if you do a 0.5-mm slice scan on an individual with a bypass graft in the leg, the difference between 0.5 and 1 mm is really enormous because you can see the actual ribbing on the graft," Clouse said.

Before CT chest pain imaging becomes routine, improvements also will be needed in reconstruction and postprocessing. White's protocol reconstructs 10 phases from the heart to capture the best phase of imaging of the coronary arteries and perform some functional images.

Although reconstruction algorithms have been streamlined, reconstructing a study consisting of 2000 or more slices can take 20 minutes or longer, which ties up the scanner if reconstructions are done on the operator's console and makes emergency department physicians wait for a diagnostic answer. Hardware changes that speed up reconstruction or shift the process offline may allow reconstructions to be done on an adjacent workstation without interrupting work flow, White said.

Ideally, emergency cardiovascular CT would incorporate one-touch postprocessing so that the 3000 images entering a workstation will generate data that allow complete assessment of the heart, including a reconstruction of the coronary arteries, measurement of ejection fraction and perhaps left ventricular perfusion, a cine loop assessment of wall motion, and even a calcium score.

Postprocessing can take a half-hour or longer, however, just to get images of the coronary arteries and pick out the proper phase while evaluating whether the arteries are stenotic. Measurement of ejection fraction takes time because radiologists have to manually segment the endocardial portion of the endocardium in systole and diastole. Postprocessing remains so slow it is a barrier to a full CT cardiac workup, White said.

Other limitations include the sensitivity of scanners to motion, especially for finding small aortic intimal injuries and peripheral emboli, Dubinsky said. Because radiologists are seeing the interior of the human body in more and more detail, they are now plagued by subtle artifacts that could be ignored in the past as well as any kind of motion-related misregistration.

THE PROMISE OF 64 SLICES

Although 32-slice CT scanners can cut through the chest in less than 30 seconds and provide high-quality images of the coronary arteries, the increased speed of 64-slice scanners will counteract motion artifacts from patients' breathing and allow gating of all chest studies. With 64-slice scanners, image acquisition will be so fast radiologists should be able to do a scan while the pulmonary arteries as well as the aorta are opacified and the

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COLLABORATION

the involvement of radiologists.

The cornerstone of collaboration is education. In order for radiologists to work in partnership with cardiologists in the heart, they must pair their knowledge of cross-sectional cardiac anatomy with an understanding of cardiac disease.

A host of organizations, from the RSNA to the North American Society for Cardiac Imaging (NASCI), offer specialized education and training in cardiovascular imaging. Several vendors also offer masters courses on the topic.

"Radiologists are as prepared as cardiologists (to perform) CT studies of coronary calcium and coronary angiograms," said Dr. Melvin Clouse, vice chair of radiology at Beth Israel Deaconess Medical Center in Boston. "Radiologists must now learn about Framingham risk scores and national cholesterol protection guidelines. We need to apply what we've learned into practice."

NASCI offers good opportunities for radiologists and cardiologists to learn more about cardiovascular CT capabilities, said Dr. William Stanford, a professor of radiology at the University of Iowa and a NASCI board member. Attendance at the organization's annual meeting has increased substantially in recent years, with a large number of cardiologists participating.

"The meeting offers a good overview of all the imaging modalities and the pros and cons of each," he said. "If a person is sitting on the fence and not sure of the methodology, they can get some answers at NASCI."

Beyond understanding cardiac disease, radiologists must also master 3D imaging in order to excel at cardiovascular CT. Extending the power of 3D through training and education is a need that continues to go unmet, according to Dr. Geoffrey Rubin, chief of cardiovascular imaging at Stanford University.

"The analogy I like to use is that of a driver's education program," Rubin said during a plenary session at the RSNA meeting focused on 3D imaging. "Interactive and intuitive modules are needed so that users can simply focus on driving and not on how to operate the vehicle." ■

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TRAUMA

heart and coronary arteries are well visualized.

"Many of our emergency patients are hyperventilating and have a rapid heart rate, so things are moving. The 64-slice scanners should be able to decrease motion artifact from cardiac, aortic pulsatile, and respiratory movement," Novelline said.

In addition to scanning through tissue volume more quickly, 64-slice scanners may increase temporal resolution by decreasing the window of data. Because 64-slice scanners have a gantry rotation of 0.4 seconds or less, they will push the limit and reduce the window of data to 0.05 seconds, which will reduce motion effects and perhaps eliminate the need for beta blockers, White said.

"When the heart rate is faster, it keeps going from systole to diastole at a fast rate, so you need better temporal resolution. The goal of the CT scanner is to decrease the temporal window so there is very little blurring. One way to overcome current scanners' limitations is by giving beta blockers to slow the heart rate down and make it more tolerant to a wider window of data. The other way is to make the temporal window smaller. Some of the reconstruction advantages of the 64-slice machines will help get that smaller window, and so will a faster gantry speed," White said.

The scanners will provide more options for image manipulation, Novelline said. With 64-slice machines, radiologists will be able to sandwich tissue sections and look at two or three sections together or stack slices in coronal or sagittal reformations, all in postprocessing when the patient is off the table.

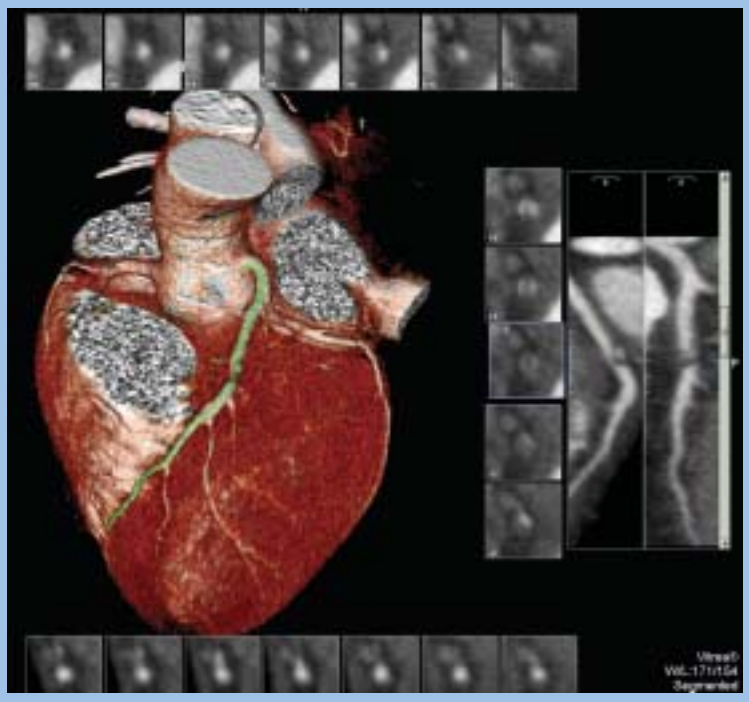
The thin slices possible on advanced CT scanners should enhance visualization of the distal coronary arteries. The size of the proximal coronary arteries is less than 4 mm, and the diameter of the distal arteries is around 2 mm. A slice thickness of 0.5 mm may make all the difference in finding the smaller distal vessels, White said.

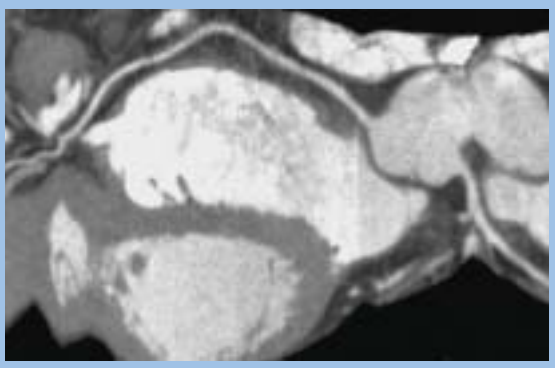
The advantages of 64-slice CT would appear to set the stage for a single noninvasive study of cardiac causes of acute chest pain. It is not clear whether MSCT will define ischemia from infarction. If it does, it may serve as a triage point for sending individuals with a single lesion in the left anterior descending artery to angioplasty and those with a stent or multivessel disease to surgical bypass.

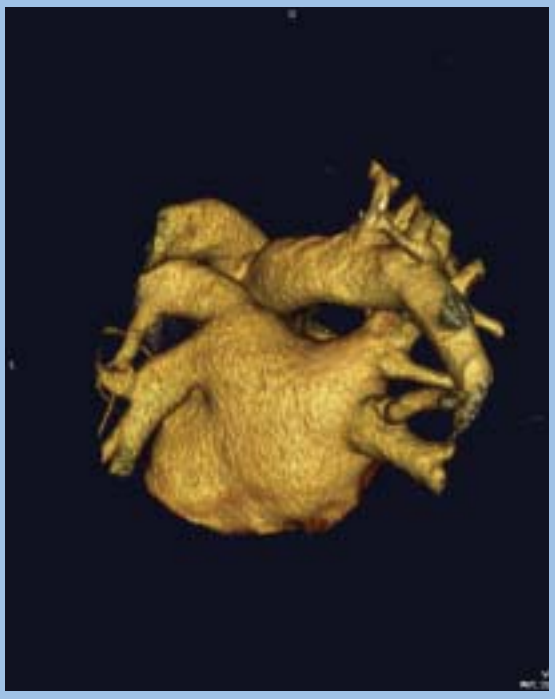
"At some point, we may collect enough data to say that CT works and to show how we can use it for chest pain evaluation. Now it's still the big frontier," Dubinsky said. ■

ERRATUM

In the story "Advances prompt rethinking of imaging priorities" in the December 2004 *Cardiovascular CT* supplement, detector collimation for evaluating patients with peripheral vascular disease should have been listed as 1 to 1.5 mm.







With the growth of high-slice scanners, interest in CT cardiovascular applications has soared. Scanners with 16 or more detector rows can acquire images with ever-improving clarity and detail. Researchers now are focusing on quantifying and characterizing plaque (top left), planning minimally invasive procedures such as pulmonary vein ablation therapy (bottom right), and assessing the patency of primary and peripheral vessels. The simultaneous growth and accessibility of 2D and 3D reconstruction algorithms (top right, bottom left, and middle) have been essential to imagers' ability to interpret and manage the rich data sets. (Provided by Fujita Health University; Steinberg Diagnostic Imaging, Las Vegas; Toshiba)