

The use of contrast media in cardiac CT

Cardiac studies are among the most challenging—and promising—applications of contrast-enhanced CT.

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The approach to cardiac computed tomography (CT) differs from that of routine CT in several key respects. First, because of the need for very high temporal and spatial resolution, we use a 16-detector-row CT scanner for all cardiac applications. We also reduce the table speed to 6 mm/sec in order to acquire enough projections to adequately reconstruct images. As a result, cardiac scanning takes longer than other applications of CT angiography (CTA), such as aortic scanning. In addition, we obtain a digital electrocardiographic (ECG) tracing during scanning, so we can retrospectively reconstruct images at a dedicated time point, typically the diastolic phase of the cardiac cycle.

Table 1 outlines the scanning protocols we use for 4-detector-row and 16-detector-row cardiac CT scanning. We use the thinnest collimation available with the 16-row CT scanner, 0.75 mm, and the shortest rotation time, 420 msec. As a result, image noise is increased. To compensate, we increase the tube current to 500 mAs from the 400 mAs we use with the 4-row CT system. A clear advantage of a 16-row CT scanner over a 4-row scanner is a halving of scan time, to 20 seconds. With

ECG pulsing—in which full X-ray power is used only in mid-diastole—the effective radiation dose delivered to the patient with the 4-row CT system is approximately 4 mSv, and approximately 5 mSv with the 16-row CT system. Both are similar to the radiation dose associated with a routine chest CT or conventional cardiac catheterization.

Figure 1 shows a comparison of three-dimensional (3D) renderings from the same patient imaged with a 4-row CT scanner and, 1 year later, with a 16-row CT scanner. The patient underwent the initial CT study as part of an evaluation for acute chest pain. On 4-row CT scanning, a stenosis in the proximal portion of the left anterior descending coronary artery was evident. She subsequently underwent cardiac catheterization and stent implantation. One year later, we evaluated stent patency using a 16-row CT scanner.

Comparing the 3D renderings, it is obvious that the image acquired on the 16-row scanner looks rougher on its surface. This is a result of increased image noise. It is equally obvious that the visualization of small arteries, such as the diagonal branches, is much clearer with the 16-row scanner as a result of its superior spatial resolution. Similarly, the

Table 1. Cardiac multidetector CT scan protocols

	4DCT	16DCT
Collimation (mm)	1	0.75
Rotation (msec)	500	420
Voltage (kVp)	120	120
Current (mAs)	400	500
Scan time (sec)	~40	~20
Effective dose (mSv)	~4	~5

4DCT = 4-detector row CT, 16DCT = 16-detector row CT

right coronary artery is too small to be visualized by the 4-row CT system, but it can be appreciated in the image acquired on the 16-row CT system.

CT angiography of the coronary arteries often detects the presence of coronary atherosclerosis, which is characterized by plaques of varying density. Low-density atherosclerotic plaques can be categorized by an enhancement of up to 50 HU, intermediate-density plaques by an enhancement of 50 to 100 HU, and calcified, high-density plaques by an enhancement of more than 350 HU.

Optimal vascular enhancement for coronary CTA is 200 to 300 HU. We performed a study to determine the effect of iodine concentration and flow rate on

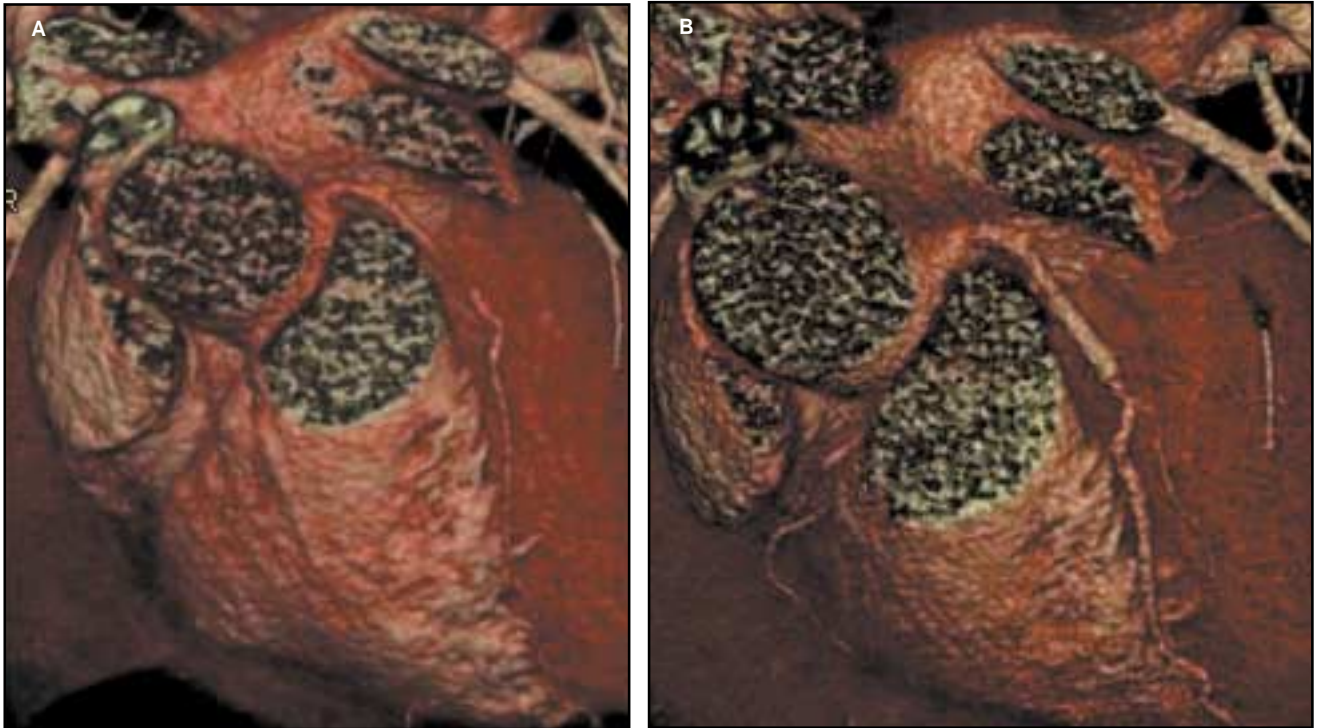


FIGURE 1. Three-dimensional renderings from the same patient imaged (A) with a 4-row CT scanner and (B) with a 16-row CT scanner 1 year later. (A) The 4-row CT scanner detected a stenosis in the proximal portion of the left anterior descending coronary artery. (B) The image acquired on the 16-row scanner shows more image noise but better visualizes small arteries, such as the diagonal branches and the right coronary artery.

enhancement density.¹ As shown in Figure 2, we found that injecting 300 mgI/mL contrast material at 2.5 mL/sec resulted in a mean left ventricular (LV) contrast enhancement of approximately 200 HU. Injecting low-concentration contrast material (300 mgI/mL) at high flow rate (3.5 mL/sec) or higher-concentration contrast material (400 mgI/mL) at a lower flow rate (2.5 mL/sec) produced a similar result: LV enhancement of approximately 200 to 300 HU. Injecting high-concentration contrast material (400 mgI/mL) at a high flow rate (3.5 mL/sec) resulted in an enhancement density of approximately 350 HU, which overlaps the enhancement density of coronary calcifications and may prevent their detection. Plotting iodine delivery rates against HU shows that for a target LV contrast enhancement of 200 to 300 HU, it is necessary to administer approximately 1 gram of iodine per second.

In addition to the iodine delivery rate, several other factors influence enhance-

ment of the LV and the coronary arteries. These include the viscosity of the contrast material, the type of peripheral access through which contrast will be delivered and where it has been placed, the blood volume as reflected by body weight, cardiac output, and the use of a saline chaser.

Patient preparation

Given that the temporal resolution of cardiac CT studies is >200 msec, it is necessary to lower the patient's heart rate to <60 bpm before the initiation of scanning, primarily through the use of beta blockers. We first ensure that the patient has no contraindications to beta blockade, such as asthma, aortic stenosis, atrioventricular block, or severe LV dysfunction. Then, immediately before scanning, we inject 5 to 20 mg metoprolol intravenously.

Figure 3 demonstrates the effect of beta blockade on contrast enhancement. Without first administering a beta blocker, we

injected a 20-mL bolus of contrast material (orange curve). We then repeated the test bolus injection after administration of a beta blocker (yellow curve). We found that beta blockade delayed the time to peak contrast enhancement by 4 seconds, and increased peak enhancement by 10%.

Figure 4 shows a patient whose heart rate upon referral for CT was 82 bpm. After injection of a beta blocker, the heart rate fell to 65 bpm, and we were able to clearly visualize the coronary anatomy, including the common trunk of the left main coronary artery, originating together with the right coronary artery from the ostium of the right coronary artery.

Timing

Accurate contrast timing is critical when imaging with a 16-row CT scanner. If scanning begins too early, contrast material will still be in the pulmonary arteries at the time of data acquisition, rather than in the LV or coronary arteries.

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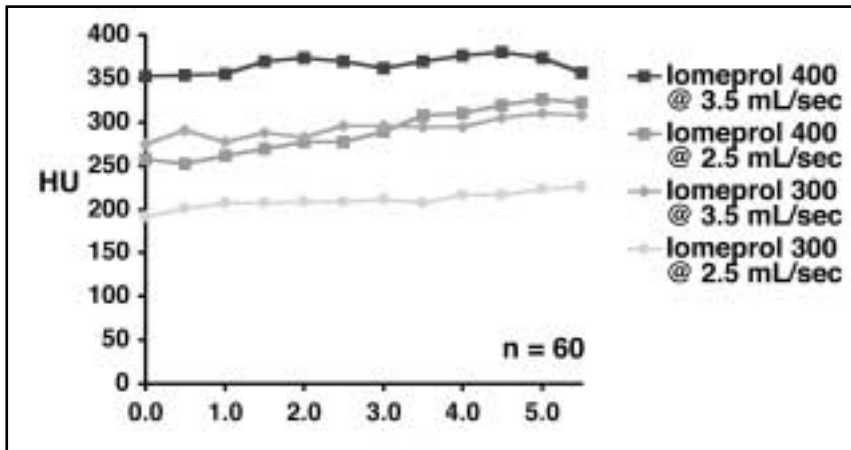


FIGURE 2. Injecting 300 mg/mL contrast material at 2.5 mL/sec resulted in a mean left ventricular (LV) contrast enhancement of approximately 200 HU. Injecting low-concentration contrast material (300 mg/mL) at a high flow rate (3.5 mL/sec) or higher concentration contrast material (400 mg/mL) at a low flow rate (2.5 mL/sec) produced a similar result: LV enhancement of approximately 200 to 300 HU.

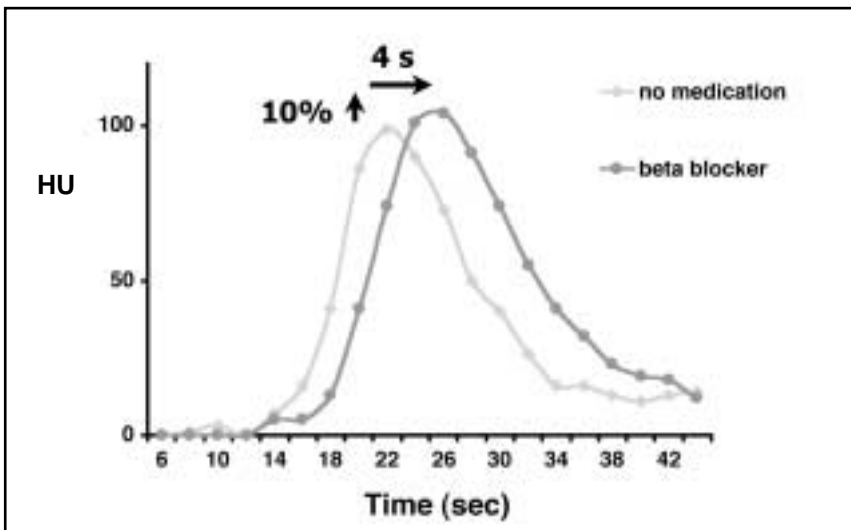


FIGURE 3. Beta blockade delays the time to peak contrast enhancement by 4 seconds and increases peak enhancement by 10%.

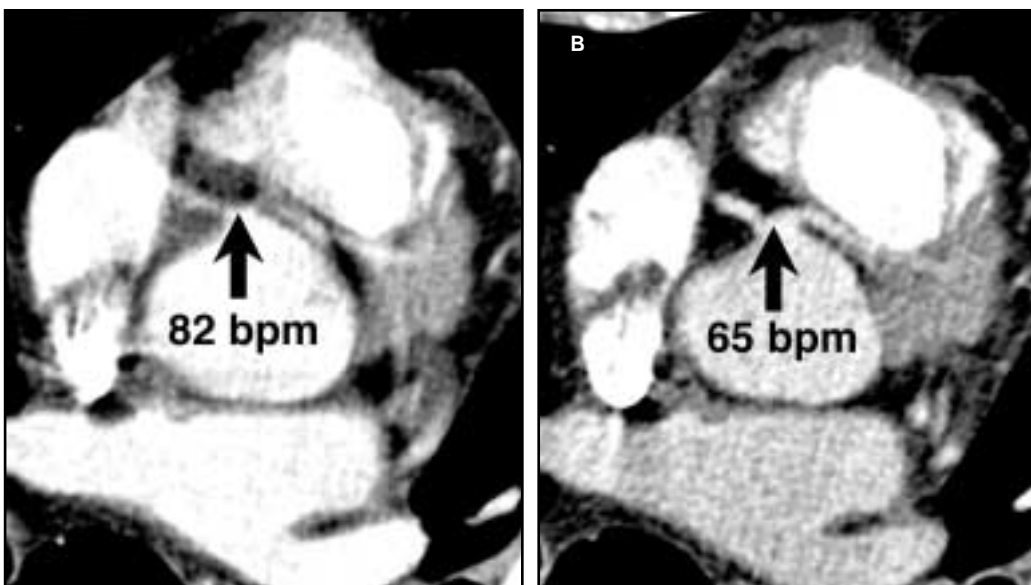


FIGURE 4. After intravenous beta blockers reduced the heart rate from (A) 82 bpm to (B) 65 bpm, CTA clearly depicts the coronary anatomy, including the common trunk of the left main coronary artery (arrows), originating together with the right coronary artery from the ostium of the right coronary artery.

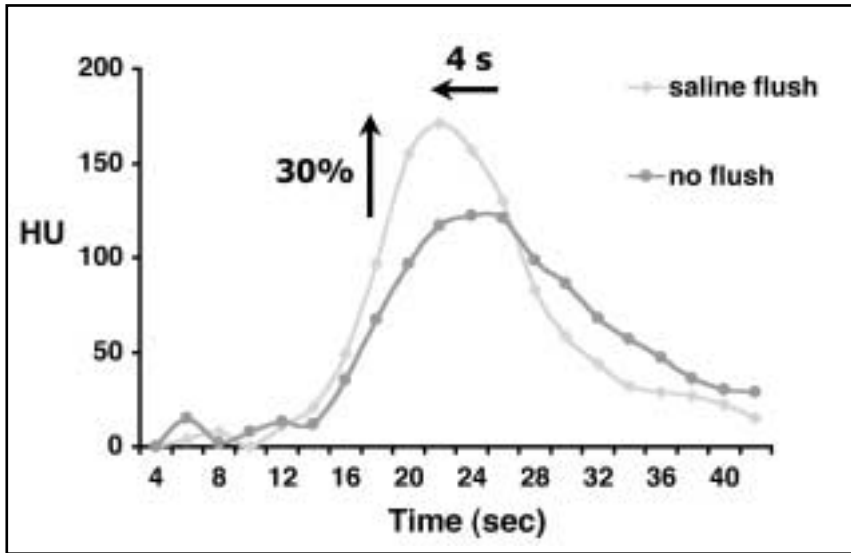


FIGURE 5. A saline chaser hastens the arrival of the contrast bolus by 4 seconds and increases peak enhancement by 30%.

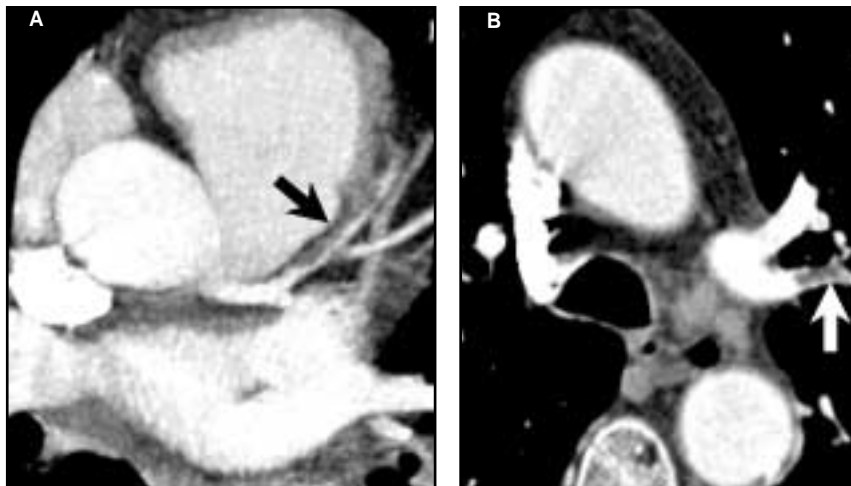


FIGURE 6. (A) In a patient with atypical chest pain, CTA detects a thrombus (arrow) in the left anterior descending coronary artery. (B) This application is similar to the established role of CTA in the evaluation of pulmonary embolism (arrow).

The use of a saline chaser, which pushes the contrast bolus forward, also influences scan timing. Figure 5 shows enhancement over time following injection of a contrast bolus with (yellow curve) and without (orange curve) a saline chaser. The saline chaser hastens arrival of the contrast bolus by 4 seconds and increases peak enhancement by 30%.

There are several advantages to using a dual injection consisting of a contrast bolus followed immediately by a saline chaser. First, if the contrast material is injected through a peripheral vein, use of a saline chaser produces a time-density curve similar to that observed with a central venous catheter, without the use of a saline chaser.² In addition, use of a saline chaser produces much more homogenous enhancement.³ Less contrast media is required.⁴ Because we are able to reduce the volume of contrast media, the risk of nephrotoxicity is reduced as well.

Osmolality

In cardiac CT, the osmolality of contrast media may be important to consider. A study by Dunkel et al,⁵ conducted in patients undergoing cardiac catheterization, has shown that the isosmolar non-ionic dimer iodixanol induces only minor changes in cardiac function, whereas the ionic dimer ioxaglate and the ionic monomer diatrizoate induce pronounced effects. Whether the osmolality of contrast media has the same effect on heart rate and, therefore, image quality in patients undergoing CTA is unknown. We are considering conducting a study to answer that question.

A study by Aspelin et al⁶ suggests that isosmolar contrast media may also reduce the risk of nephrotoxicity, at least in patients with chronic renal insufficiency undergoing cardiac catheterization. We are now testing whether that observation can be duplicated in patients undergoing CT scanning. The study is enrolling patients with a baseline creatinine >1.5 mg/dL. Regardless of the type of CT examination, patients are injected with 100 mL of

Table 2. Contrast protocols for cardiac multidetector CT

	4DCT	16DCT
Nonionic dimers (mgI/mL)	320	320
Test bolus (mL)	20	20
Scan delay (sec)	0	+5
Contrast volume (mL)	120	80
Flow rate (mL/sec)	3	3
NaCl (mL)	50	50

4DCT = 4-detector row CT, 16DCT = 16-detector row CT

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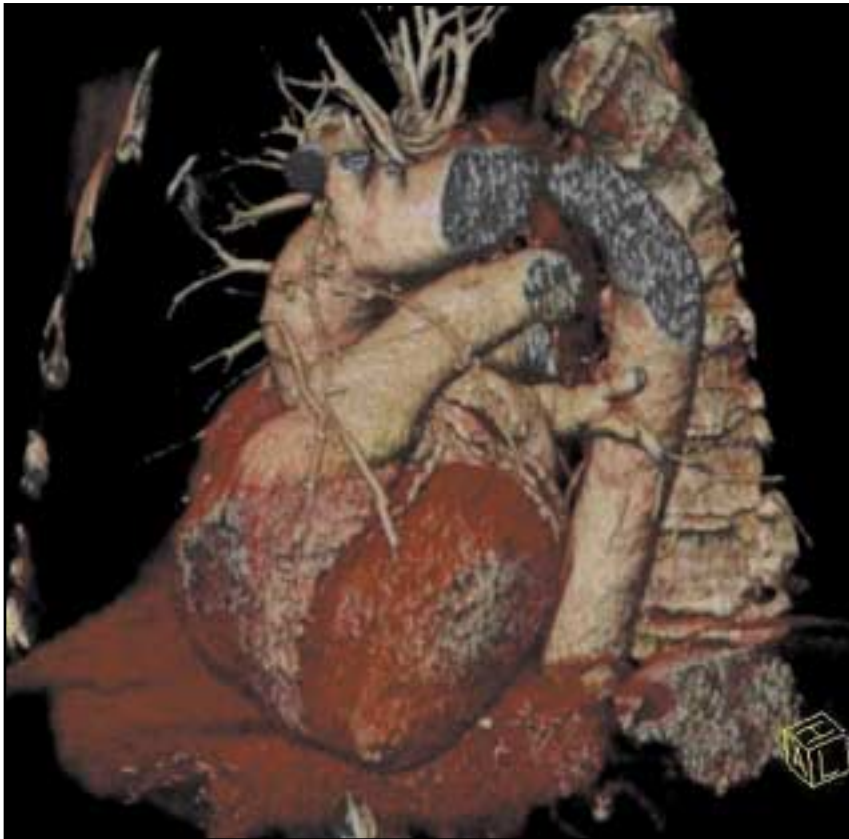


FIGURE 7. Assessment of bypass graft patency is a common application of CTA.

270 mgI/mL contrast material at a flow rate of 5 mL/sec. Patients are followed-up for 7 days after scanning.

Preliminary data from the first 20 patients demonstrate no increase in serum creatinine following exposure to isosmolar contrast media. In fact, the mean serum creatinine level decreased from 1.7 mg/dL at baseline to 1.4 mg/dL at 7 days.

Contrast administration

Table 2 details our protocol for administration of contrast media in multidetector cardiac studies. We use contrast media composed of a nonionic isosmolar dimer at a concentration of 320 mgI/mL. We determine the circulation time by injecting a 20-mL test bolus, then add another 5 sec to the bolus arrival time to allow the contrast media to reach the LV system. We then inject 80 mL of contrast material at a flow rate of 3 mL/sec, followed by a 50-mL saline chaser and begin image

acquisition after the specified delay. The resulting dataset produces superb two-dimensional (2D) and 3D images.

The future

Cardiac CT is unlikely to be used to evaluate the large number of patients with chronic stable angina, as it is unable to accurately grade coronary artery stenoses. It shows great promise in the evaluation of patients with acute or atypical chest pain, however. In this group of patients, CTA can detect intracoronary thrombus (Figure 6), an application similar to its established role in the evaluation of pulmonary embolism.

In addition, studies comparing CTA with coronary angiography have determined that CTA has a high negative predictive value for significant coronary artery disease.⁷ If this proves to be true for symptomatic patients with only low-to-intermediate pretest probability of

coronary artery disease, CTA may reduce the need for invasive coronary angiography in such patients.

CTA also has a promising future in screening for coronary artery disease in asymptomatic but intermediate- to high-risk patients. By detecting variations in the enhancement density of coronary lesions, CTA has the potential to identify vulnerable plaque, with its lipid core and fibrous cap. In this way, CTA may guide the aggressiveness of risk factor modification in asymptomatic patients.

Finally, we often use CTA in the assessment of coronary artery bypass grafts, as it enables us to examine with high spatial resolution both arterial and venous grafts (Figure 7). It is a powerful tool for studying coronary anomalies, which occur in 1% to 2% of the general population. We are increasingly using CTA to define the anatomy of the pulmonary veins, in conjunction with electrophysiological procedures.

References

1. Becker CR, Hong C, Knez A, et al. Optimal contrast application for cardiac 4-detector-row CT. *Invest Radiol*. In press.
2. Hittmair K, Fleischmann D. Accuracy of predicting and controlling time-dependent aortic enhancement from a test bolus injection. *J Comput Assist Tomogr*. 2001;25:287-294.
3. Hopper KD, Mosher TJ, Kasales CJ, et al. Thoracic spiral CT: Delivery of contrast material pushed with injectable saline solution in a power injector. *Radiology*. 1997;205:269-271.
4. Haage P, Schmitz-Rode T, Hubner D, et al. Reduction of contrast material dose and artifacts by a saline flush using a double power injector in helical CT of the thorax. *AJR Am J Roentgenol*. 2000;174:1049-1053.
5. Dunkel JA, Bokenes J, Karlsson JO, Refsum H. Cardiac effects of iodixanol compared to those of other nonionic and ionic contrast media on the isolated rat heart. *Acta Radiol*. 1995;399(Suppl):142-154.
6. Aspelin P, Aubry P, Fransson SG, et al. Nephrotoxicity in high-risk patients study of iso-osmolar and low-osmolar non-ionic contrast media study investigators. Nephrotoxic effects in high-risk patients undergoing angiography. *N Engl J Med*. 2003;348:491-499.
7. Nieman K, Cademartiri F, Lemos PA, et al. Reliable noninvasive coronary angiography with fast submillimeter multislice spiral computed tomography. *Circulation*. 2002;106:2051-2054.

Discussion

ELLIOT K. FISHMAN, MD: That's great. Any specific questions?

S. JAMES ZINREICH, MD: I was a little curious about the contrast protocol; you're not triggering this, you're using a test bolus?

CHRISTOPH R. BECKER, MD: We are using a test bolus.

DAVID P. NAIDICH, MD: How are you actually doing that? It's not clear. You're using 20 mL, but you're acquiring images at what time frame?

BECKER: We are acquiring the images at every second. I know this is quite a lot. Not only do we do it at every second, but we do this for 40 seconds. What is very important is not to let the patient hold the breath, because if you are doing so, you are forcing people's Valsava maneuver and you get a different time density curve that does not allow you to conclude what will be the final aspect.

SANJAY SAINI, MD: Are you measuring the aorta?

BECKER: The ascending aorta, yes.

SAINI: Why not use bolus tracking?

BECKER: Bolus tracking? You are right, it works pretty much the same way, and it's a robust technique. Our technicians liked the bolus tracking much more than the test bolus. But for research purposes, to learn more about this delay factor, we currently are using the test bolus just to gain more experience in this, not in a well-determined manner.

NAIDICH: You are reducing the dose, in the actual acquisition parameters, as you are doing these tests?

BECKER: Yes, it's a low dose acquisition.

KYONGTAE T. BAE, MD, PhD: If you use the test bolus out, you ask patients not to hold their breath?

BECKER: For the test bolus, you could breathe normally.

BAE: Right, but when you do real examination, you want the patients to hold their breath.

BECKER: Yes.

BAE: Do you think that would be something to make a difference?

BECKER: No, not really. As I said,

we are adding 5 seconds to the peak arrival time of the test bolus. If you are requesting the patient to hold his or her breath initially when the contrast media is injected, you have 10 seconds prior to the scan. By then, the result of the maneuver has already finished, and he has a normal circulation. So then this Valsava maneuver doesn't really take any effect anymore, and you have a rather homogenous enhancement.

ZINREICH: What is the correlation between calcified plaques and the coronary wall and luminal stenosis?

BECKER: Well, actually there has been a lot of work done already from the electron beam CTA without contrast. As a simple rule of thumb, until you see the rest of the lumen in CTA, you are pretty confident to rule out the significant stenosis in this particular segment.

But once you have a dense clot of calcium in the coronary artery that does not allow you to see the residual lumen, you have a positive predictive value of approximately 50%, so you can get a good point on whether or not there is stenosis.

W. DENNIS FOLEY, MD: Perhaps I have an explanation as to why the saline chaser would increase the aortic attenuation on a test bolus. Well, not so much in the test bolus, but let's take it to the definitive bolus—would you expect that to happen?

BECKER: Yes, that is a pretty good point. As a rule of thumb, of course, the smaller the amount of contrast media you are injecting, the higher the benefit of using a dual injection. Well, this 30% is certainly true for the test bolus, and I would expect the benefit of a dual injection and a scan that lasts 20 seconds in the range of 10% or so, but we haven't finally determined this. But this will be also part of our further studies.

BAE: If you see this curve, and then your next slide showing the Hoppers paper, you get more homogeneous enhancement with saline chase. But if you go back to your slides, then it looks

like saline chase is not more homogeneous than flush.

BECKER: I need to say that the saline chase can be somewhat cumbersome. Because we have seen, if you are pushing the contrast media further, you have a rather long scan range and you get a kind of washout.

If you are doing a runoff study, you get a kind of washout in the distal part of the arteries as well. It happens pretty much the same way, so particularly if you have a long scan range, it is not an advantage to use a saline chaser. It's only an advantage if you have a small bolus and a small scan time.

BAE: I think you have to make sure that if you inject a certain amount of iodine, then you can get the saline flush benefit. But if you try to cut that out, and replace with a saline, at the tail end you may have a washout.

BECKER: Exactly, exactly. We have seen in CTAs of the abdomen, for instance, that we have a complete washout of the femoral arteries at the end of the scan.

NAIDICH: When you're doing an aorta, say someone has a question on thoracoabdominal aneurism or it is a question of dissection and how far it goes, are you altering your protocoling when you're starting from the top of the arch and going down to the bifurcation? Are you changing the method by which you give contrast, and acquisition protocol, and so forth, to account for the fact that even on a 16-detector, you are really talking about a huge volume of data acquisition?

BECKER: Actually, amazingly, with the 16-row CT scanner, the scan time is not getting as short as one may expect, because the tendency is also to get the advantage of highest spatial resolution. So, you are using thinner concentration than you have used before. So the range of the entire scan toward abdomen would last 25 to 30 seconds, even with the 16-row scanner.

So, in this respect, there is not so much difference between these two scanners,

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in particular in dissection. The same holds true for congenital heart disease. We are using the test bolus all the time because it's hard to really predict when the arrival is in the different lumen, and in the different heart chambers in congenital heart disease. So in this respect, we choose a more dedicated approach.

NAIDICH: Are you using 1-mm collimation to cover that entire distance?

BECKER: Well, in every CTA we use the thinnest collimation available.

NAIDICH: Why are you doing that? Are you changing the rate at which you are giving contrast? It's basically the same across the board?

BECKER: Well, actually, between the 4- and 16-row CT scanner, the reduction of scan time is roughly 15%. So we are also cutting down the amount of contrast injected by 15%. Or, what we are doing is keeping the amount of contrast media the same, but injecting it at the higher flow rate.

NAIDICH: You're not changing the duration?

BECKER: No.

FISHMAN: I want to go back to emphasize two points, specifically for cardiac imaging. I know you men-

tioned that everyone gets beta blockers, which is what we are doing as well. But you did mention isosmolar contrast and heart rate change. How significant a factor is that?

BECKER: Well, I need to refer to one study that has been performed with cardiac catheters. Indeed, I don't know the effect this will have on the CTA studies. This will be one of our future projects.

FISHMAN: Just to interject, we've looked at the same issue: you give beta blockers, and you are seeing heart rates at about 60. First of all, just putting the machine on, I think, raises people's heart rate immediately, so that is one thing we've seen. But you get the heart rate down to 60, you start injecting the contrast, and you are watching it, and it is 120 right away. Again, typically for 16-slice CT, you like it to be under 90. But we found the same thing, that going to iso-osmolar contrast does have less of an effect.

The other thing to re-emphasize is the issue of different contrast concentrations. Is there a point at which there's too much iodine? In the cardiac imaging, your results have been that just going to higher concentrations isn't going to work out. Can you just expand on that a bit?

BECKER: Well, actually, that's true. The higher the iodine concentration, the better its detection of the small vessels, and this is true for the pulmonary arteries, and I have hardly seen any calcifications in the mesenteric or visceral arteries.

So, we are using the high injection rates for these particular areas. But for the coronary arteries, there has been some work done indicating that you are able to quantify the calcifications in the CTA images. But this can only be done once you are really able to delineate these classifications, and therefore the enhancement has to be no higher than 300 HU.

BAE: You said that high concentration contrast will result in less homogeneous management. So with the high concentration of contrast, you have more variation?

BECKER: Right, with the high concentration (400 mgI/mL) injected at 3.5 mL/sec, you see a lot of scatter, most likely due to the viscosity. I need to re-emphasize that the contrast media had not been warmed up. We are now warming up all the contrast media. This is, of course, of concern here.

FISHMAN: Okay, thank you very much.