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CONTINUING EDUCATION FOR MEDICAL PROFESSIONALS

The Current Status and Future of Coronary CT Angiography

by David A. Dowe, M.D.

LEARNING OBJECTIVES

Upon completion of this activity, participants should be able to:

- Select the proper patients and prepare them for CCTA.
- Use the correct technique to perform CCTA.
- Compare the diagnostic utility of CCTA with stress tests and coronary catheterization.
- Describe how a 64-slice scanner will affect CCTA.

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In 2001, 3.51 million cardiac catheterizations were performed in the U.S. Of these, 3.02 million were done to visualize the coronary arteries. Only 9% were done on an emergency basis. The majority, 1.73 million, were done for diagnosis only. Yet every year 150,000 Americans will die a sudden death related to acute coronary syndrome, and hundreds of thousands more will experience a myocardial infarction as the first sign of coronary artery disease. What is needed is a noninvasive, minimal-risk, outpatient procedure to detect the early signs of coronary disease so that risk factor modification and medical management can be initiated early enough to reduce the numbers of patients experiencing acute coronary syndromes; i.e., sudden death or myocardial infarction.

This procedure must also guide the appropriate patients to cardiac catheterization labs or operating rooms where percutaneous intervention or surgery can be carried out on an elective basis. This procedure would prevent the 40% to 50% of negative diagnostic coronary catheterizations that are performed each year in the U.S. The potential cost savings to the healthcare system, not to mention the risk avoidance for patients, is staggering if one estimates the cost of 865,000 negative diagnostic cardiac catheterizations compared to the cost of the same number of negative coronary CT angiograms (CCTA). This paper will discuss the technique used to perform reliable, complete, coronary circulation CTA with a near zero complication rate. It will also discuss the clinical value of CCTA compared with alternative procedures, its diagnostic capability compared with the same alternative procedures, and the future of CCTA, especially since we are embarking on the era of volume CT scanners.

TECHNIQUE

As with other imaging studies, the success rate of a CCTA study is increased by appropriate patient selection. Although the typical radiation dose is much less than—or, in the worst case scenario, equivalent to—a cardiac catheterization,[1] it is not trivial. For that reason we do not perform CCTA in patients without cardiac risk factors or symptoms. In addition to those with the traditional risk factors of family history, smoking, hypertension, diabetes mellitus, and hypercholesterolemia, we will perform CCTA on patients who have elevated C-reactive

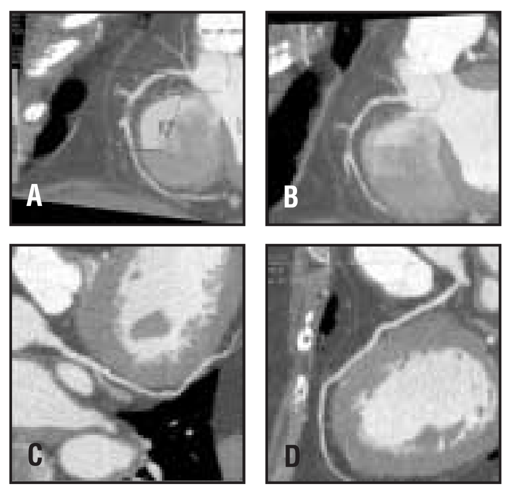

Figure 1. *Plaque detection and characterization. A: High-grade stenosis of right coronary artery by fibrous plaque. Color coding confirms that plaque is mostly fibrous. B: Fibrous plaque without color coding. C: Left circumflex artery. D: Left anterior descending artery.*

protein, elevated homocysteine levels, small LDL particle size with normal or near normal cholesterol levels, and other inherited syndromes. Absolute contraindications are a history of allergy to iodinated contrast that has failed a steroid prep; pacemakers secondary to the artifacts from the leads; atrial fibrillation, bigeminy, trigeminy, and other rhythm disturbances manifesting as an irregular heart rate; heart block; and renal insufficiency with a serum creatinine level of >1.8. Patients with chronic obstructive pulmonary disease (COPD) or reactive airway disease receive calcium channel blockers instead of beta blockers as their prep.

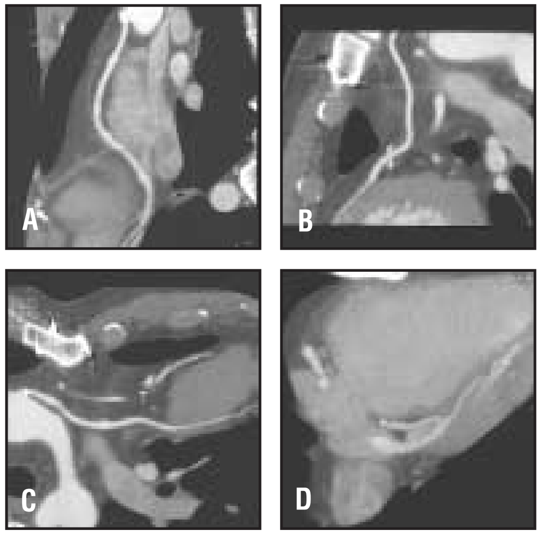

Figure 2. *Coronary artery bypass grafts. Bypass grafts are scanned at 16 x 1.25 mm in order to cover the greatest volume of tissue with a reasonable breath-hold time. A: Saphenous vein to the posterior descending artery. B: Left internal mammary artery to the left anterior descending artery. C: Saphenous vein to the first diagonal. D: After reconstruction, the data set may be rotated to image the anastomoses in profile.*

All patients receive oral medications to slow their heart rate to the acceptable goal of <62 beats per minute. Most patients receive 100 mg of metoprolol orally one hour prior to the exam. If, one hour later, the patient's heart rate is between 62 and 70 bpm, he or she will receive an additional dose of 50 mg metoprolol and the exam is performed 30 minutes later. If the heart rate is >70 bpm after the first dose, an additional 100 mg of metoprolol is administered and the exam is performed 30 minutes later. If a patient has reactive airway disease, the same regimen is used, but we substitute 240 mg orally administered short-acting verapamil for the metoprolol.

At this time the patient has an 18 to 20-gauge angiocatheter placed in an antecubital vein. We never venture away from the antecubital region secondary to inadequate bolus formation or flow rates inherent in other areas. If there is no antecubital venous access, a short 5-French polyurethane PICC line is placed in an axillary vein using ultrasound or venogram guidance.

The patient is then brought into the CT suite and two liters of oxygen are administered by nasal cannula. This ensures that the patient will achieve maximal oxygen saturation during the breath-hold. This translates into a lower and more stable heart rate during the CCTA run.

CCTA is essentially a five-step procedure. First, we obtain an anteroposterior scout image. Second, we obtain a lateral scout image. Using these images for localization, we perform the third step, which is a spiral, noncontrast run from the inferior aortic arch through the inferior aspect of the heart. This is done by obtaining 5-mm cuts using only 40 mA to limit the radiation exposure. The location of the left main coronary artery is selected off this run and the fourth step, the manual timing bolus run, is performed. Just prior to this run we administer one spray of nitroglycerin 1/150 grains sublingually. We do this in an attempt to create a physiologic state similar to what would be present at the time of coronary catheterization. We noticed an immediate improvement in cath correlation with CCTA when we began using nitroglycerin.

We then inject 20 cc of Visipaque 320 followed by 20 cc of saline intravenously. Slices 5 mm thick are obtained at the left main artery level every two seconds. Visipaque 320 is the only contrast we use for CCTA because of its low osmolality and resultant decreased warm sensation in the patient's chest. Patients are alarmed by this symptom when using higher density contrast, resulting in an elevated and sometimes irregular heart rate during the CCTA run.

We currently use the Medrad Stellant injector for our CCTAs. An ellipse cursor is placed over the aortic root and the time to peak enhancement is calculated. We then add eight seconds: five seconds for the time of injection of the 20-cc bolus at 4 cc/sec and three seconds for the contrast to travel from the aortic root and fill the coronary arterial circulation. Typically, the total circulation time is between 20 and 30 seconds. The contrast dose for the CCTA, the fifth and final step, is determined by the circulation time. If the total circulation time, after adding the eight seconds, is ≤30 seconds, the patient will receive 80 cc of Visipaque 320 followed by 50 cc of saline intravenously. If circulation time is >30 seconds, the patient will receive 100 cc of Visipaque 320 followed by 50 cc of saline intravenously.

The scan parameters for CCTA are then selected. It cannot be overemphasized how critical physician involvement is during this process. Each CCTA is "tailor-made" for each patient depending on body habitus, heart rate, lung status, and breath-hold ability. Patients with a heart rate <60 bpm are scanned using single-sector analysis. Patients with a heart rate between 60 and 75 bpm are scanned using two-sector analysis. Patients with a heart rate >75 bpm are encouraged to reschedule the exam to a future time when sedation can be administered. Patients whose heart rate remains at >75 bpm after the beta-blocker regimen and sedation are scanned using four-sector analysis.

We attempt to scan all patients at 0.625-mm slice thickness. Those routinely scanned at 1.25 mm are patients with bypass grafts secondary to the large area it is necessary to cover and patients needing a shorter breath-hold, such as those with COPD and those who are obese. With obese patients signal-to-noise is a major issue. Some CT manufacturers will push faster gantry speeds or thinner slices than we use. These factors may actually work against you if you do not have the generator capacity to get enough photons into the smaller voxel or the same-sized voxel in the shorter period of time available with thinner slices or faster gantry rotation times. For obese patients we slow the gantry speed to 0.5 second widen the field-of-view, use 1.25-mm slice thickness, and maximize the technique, all in an effort to improve the signal-to-noise ratio. For all other cases the gantry speed is 0.4 second. We always use 120 kVp.

Tube current is determined by the patient's body habitus. Small patients get 500 mA, average-sized patients get 650 mA, and large patients are scanned at the maximum current available, frequently >750 mA. The single most important scan parameter for a successful CCTA is mA. It is this parameter that we use in determining which CT scanner to purchase if we intend to perform CCTA. One never really knows in advance which patient's heart rate will vary during the CCTA run. Because of this we keep tube current at the maximum desired setting, depending on the patient's body habitus, from 40% to 80% of the RR interval. In the remaining portion of the cardiac cycle the tube current is adjusted to be 20% of the maximum mA. As an example, an average-sized adult would receive 650 mA during the 40% to 80% window of the RR interval and 130 mA during the rest of the cardiac cycle. EKG dose modulation may reduce radiation exposure up to 50% in patients with low heart rates.

After the CCTA run has been completed, the patient's IV catheter is removed and vital signs are obtained. If the vital signs are adequate, the patient is immediately discharged. To date we have performed more than 800 CCTA exams with no complications from the beta-blockers or calcium channel blockers. We have had two episodes of reflex tachycardia secondary to the nitroglycerin that we overcame simply by waiting five minutes. We have also had two patients complain of postnitro headaches.

The CCTA data are then reconstructed in multiple phases of the RR interval without reexposing the patient to radiation. If the patient's heart rate was steady, we reconstruct three phases using 70% to 80% of the RR interval with the window centered every 5%. If the patient's heart rate varied, we reconstruct nine phases using 40% to 80% of the RR interval with the window centered every 5%. Keep in mind that if you employ EKG dose modulation, the remaining portions of the cardiac cycle will be obtained at a much lower mA and are therefore not suitable for reconstruction of the coronary arteries. These data are acceptable to use for functional cardiac CT work.

The multiphase data are then sent to the workstation to simultaneously reconstruct the images in multiple phases without reloading the slice data (simultaneous multiphase reconstruction), interleave vessel segments from different phases into a single composite image (phase registration), and reconstruct multiple vessels simultaneously (simultaneous multivessel reconstruction). This latter feature offers huge time savings when reconstructing the left coronary circulation. Images of the left main artery, the left anterior descending artery (LAD), the first and second diagonal branches of the LAD, the left circumflex artery (LCX) and its first obtuse marginal branch, the right coronary artery (RCA), and the posterior descending artery (PDA) are routinely visualized. Frequently, more than two diagonals and more than one obtuse marginal are identified and examined. All vessels are visualized in multiplanar reformats (MPRs), maximum-intensity projections (MIPs), and 3D volume-rendered images as well as a "lumen view." This latter view takes every vessel reconstructed, snaps it straight and rotates the vessel 360°. This is a significant advantage over planar imaging techniques such as cardiac catheterization, which look at images in a single plane. Planar imaging more commonly will miss eccentric stenoses and suffer from overlapping vascular structures. It is important to image the vessels in the appropriate window/level settings. We use four different settings: 800/100 for routine CCTA, 1200/200 for heavy calcified plaque burden, 1400/300 for stents and detecting instent restenosis, and 600/50 for exams on obese patients if there are signal-to-noise issues.

CLINICAL VALUE AND COMPARISON WITH ALTERNATIVE PROCEDURES

CCTA is very valuable in numerous clinical settings. It detects and characterizes atherosclerotic plaques, detects and measures stenoses, evaluates the status of bypass grafts and stents, and detects ancillary findings that may be causing symptoms.

Coronary artery calcium scoring has become popular for a number of reasons. It is easily done and can be performed on either expensive electron beam scanners or on more economical single-slice spiral scanners. It is easy to interpret, and it does give some valuable information. Shaw[2] published the results of a study of more than10,000 patients in whom coronary artery calcium scoring was an independent predictor of mortality. Our experience is that the calcium score is potentially misleading throughout its spectrum of values, and we elect not to perform this exam in lieu of the "total plaque assessment" of coronary CTA. We have a number of patients with stenoses >70% caused by soft plaques who have a calcium score of zero, patients with soft plaque stenoses throughout the spectrum of values, and patients with no stenoses present but higher than 90th percentile calcium scores. Budoff[3] has shown that patients with high calcium scores will stay on statins longer than those with zero or normal-range scores. Although it has yet to be quantified, CCTA is a more accurate test.

The gold standard for detecting soft plaque in the coronary arteries is intravascular ultrasound. IVUS, which is done as part of a catheter coronary angiogram, is invasive. It involves placing a large catheter in the coronary arteries and requires a greater degree of anticoagulation, which in turn changes the groin management and prolongs the hospital stay. It is also possible only with the use of expensive equipment and is reimbursed poorly, if at all. Leber[4] examined 58 vessels and compared CCTA's ability to detect plaques to that of IVUS. In a comparison with IVUS, he found that CCTA was 78% sensitive for hypo- and hyperechoic plaques, respectively, and 95% sensitive for detecting calcified plaques. Achenbach[5] also compared CCTA with IVUS in 83 vessel segments and reported that CCTA is 78% sensitive for detecting noncalcified plaques and 94% sensitive for detecting calcified plaques. More important, he states that when limiting the comparison to proximal vessels, CCTA is 91% sensitive for noncalcified plaques, 95% sensitive for calcified plaques, and 92% sensitive for any plaques. The clinical significance of this is that the incidence of sudden death decreases significantly if a plaque ruptures distal to the first septal perforator of the LAD. The hope is that a 92% sensitivity for any proximal plaque will aid in detecting these plaques early in asymptomatic, at-risk patients so that initiating aggressive medical management may have a significant impact on the number of patients experiencing acute coronary syndrome.

Once plaques are detected they may be characterized by measuring their Hounsfield units. The HU ranges for atheromatous and fibrous plaques reported by Leber[6] have an approximately 30% standard deviation, but one must keep in mind that atherosclerotic plaques are rarely homogeneous on pathologic evaluation. They frequently contain a mix of atheromatous, fibrous, and calcified tissue. The significance of detecting and characterizing plaques is that early, more vulnerable plaques are more likely to be noncalcified (Figure1). When these plaques are detected by CCTA, clinicians are much more likely to initiate or maximize statin therapy, and some will add ACE inhibitors to the medical regimen, presuming that the patient has underlying endothelial dysfunction.

Most of the literature comparing the sensitivity of CCTA to catheter angiography for detecting a >50% stenosis is based on results obtained using four-channel multidetector scanners. Only two papers compare 16-slice CCTA with catheter angiography. Nieman[7] found that CCTA was 95% sensitive, 86% specific, and had an 80% positive predictive value (PPV) and a 97% negative predictive value (NPV) when compared with catheter angiography. Ropers[8] published similar data of 92% sensitivity, 93% specificity, 79% PPV, and 97% NPV for CCTA. Ropers, however, eliminated 12% of vessel segments that could not be evaluated on the basis of image quality. Nonetheless, both papers are significant in that the data show that CCTA exceeds the performance of nuclear medicine stress tests for sensitivity of a >50% stenosis. This raises the question of whether 16-slice CCTA should be the first-line test in evaluating patients for coronary artery disease. Larger comparative studies are under way.

Coronary artery bypass grafts are easily examined by CCTA (Figure 2). These structures, whether arterial conduits or venous grafts, are all larger than the native coronary vessels, have no branches, and are extracardiac in location, which greatly diminishes the chances of their visualization being compro-

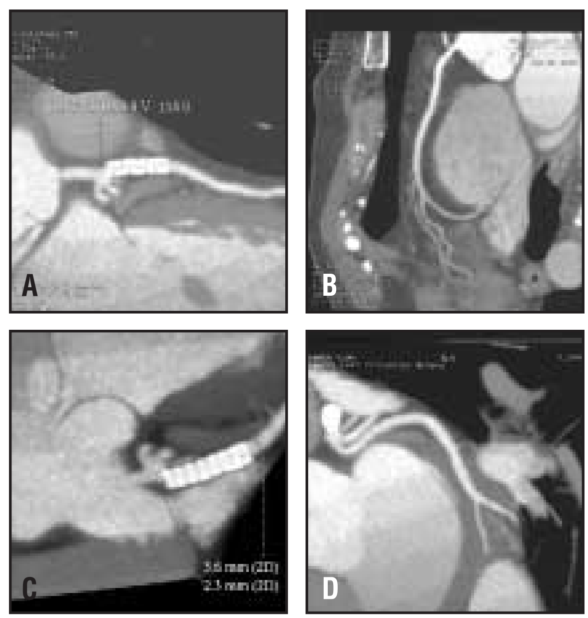

Figure 3. *Coronary stent evaluation. Stents are best evaluated by scanning at 16 x 0.625 mm and viewing the images on different window/level settings to optimize visualization of contrast and the stent. All stents should have a square or flared end. A: Example of incomplete deployment of the proximal stent with secondary intimal hyperplasia. This was likely deployed deliberately in such a fashion to avoid compromising the ostium of the first diagonal branch. B: Minimal plaque in the right coronary artery. C: No significant stenosis results from the intimal hyperplasia. D: Normal left circumflex artery.*

mised by cardiac motion. In our experience, coronary artery stents are also easily imaged by CCTA (Figure 3). Although no large study exists comparing stent patency on CCTA versus catheter angiography, our experience when comparing the two studies has been excellent. We attribute this to our technique of using 0.625-mm slice thickness, maximizing mA (resulting in less beam-hardening artifact), and visualizing the vessels using a stent-appropriate window/level of 1400/300. When we detect instent restenosis, marginal stent restenosis, or bypass graft stenoses or occlusions we always follow CCTA with a stress test. Our experience is that the heart heals after percutaneous or surgical intervention and the stress tests are almost always normal with these CCTA abnormalities. One should not assume that these findings are resulting in myocardial hypoperfusion and rush to catheter angiography.

At the time this article was written we had performed over 800 CCTA exams. In reviewing the results of these studies we have discovered an incidence of 10% ancillary findings on these exams (Figure 4). This has led us to perform a complete CT chest examination immediately after the CCTA run. Some of our most significant findings are pulmonary emboli, lung cancer, esophageal cancer, pancreatic carcinoma, Hodgkin's lymphoma, mesenteric panniculitis, arrythmogenic right ventricular dysplasia, and a pseudoaneurysm of the inferior left ventricular wall. The significance of these findings is underscored by their serious nature and the fact that many of them may present as chest pain. CCTA is extremely useful not only in detecting ancillary findings but also in clearing the coronary arteries in patients with these findings. The frequency of these findings makes it mandatory that someone with training in chest CT imaging review all CCTA studies. This, together with the necessary workstation skills and appreciation of common CT artifacts, may result in radiologists making significant inroads in cardiac imaging and actually gaining "turf" from cardiologists.

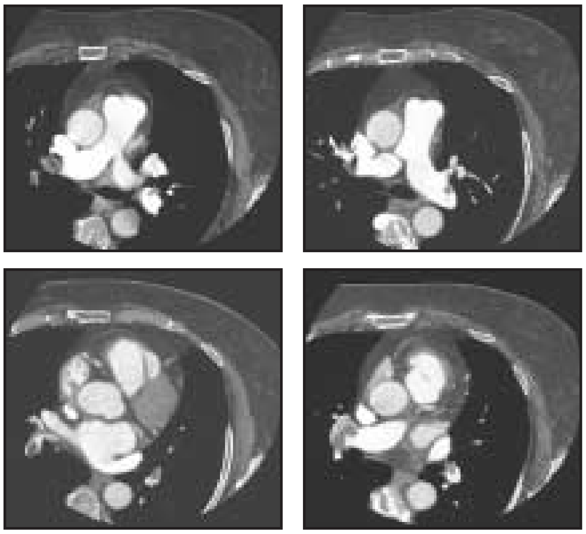

Figure 4. *Ancillary findings. Pulmonary emboli are identified on the axial images in a patient complaining of chest pain and shortness of breath.*

When summarizing the results of our CCTA exams, we use four triage protocols: negative, mild plaque without stenoses, moderate plaque with a 50% left main stenosis or a 50% to 70% stenosis elsewhere, and severe plaque with any stenosis >70%. We recommend stress test correlation in all cases of moderate disease and catheter angiography in most cases of severe disease. We find that using CT scanners capable of high mA (>650), we can achieve a complete CCTA exam on the first attempt in 95% of patients. We succeed on the second attempt in 80% of the remaining patients by delaying the exam and using sedation. Also, the high-mA CT scanners have decreased the number of patients requiring stress test follow-up from 26% to 13% and those requiring cardiac catheterization follow-up from 7% to 3%. We attribute this to improved image quality secondary to improved temporal and spatial resolution.

CONCLUSION

Sixteen-slice CT scanners and the supporting workstation software have made CCTA possible in an overwhelming majority of patients. Limitations on the proliferation of this exam are not technological but educational; i.e., the number of sites that can perform CCTA on a high level. The early literature indicates that CCTA may surpass stress tests as the first exam a patient with potential CAD receives because of its sensitivity in detecting stenoses when compared to catheterizations.

More than 3.5 million cardiac catheterizations are performed in the U.S. each year; more than three million are for coronary artery disease, and more than half of these are for diagnosis only. With only 9% of catheterizations being performed on an emergency basis and with CCTA having a 97% negative predictive value, one could easily make a case that nonemergency diagnostic catheterizations should be preceded by CCTA. With 40% to 50% of cardiac catheterizations being negative or near negative, these exams, with their high cost and low but inherent complication rate, will no longer be necessary. The potential cost savings to the healthcare system are enormous as CCTA is reimbursed at rates that are 10% to 12% of the rates for coronary catheterizations. CCTA holds great though unproven promise of affecting the incidence and mortality of acute coronary syndrome through noninvasive plaque detection and characterization.

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