The Emerging Use of 16- and 64-Slice Computed Tomography Coronary Angiography in Clinical Cardiovascular Practice

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Multi-slice computed tomography (MSCT) coronary angiography is an imaging modality that can identify patients with both soft and hard plaque, supplementing the information gleaned from an ordinary coronary calcium scan and classic risk-factor assessment. Clinicians now have the tools to identify the presence of coronary artery disease (CAD) in the presymptomatic phase, as well as those needed to help identify the etiology of pain syndromes in patients presenting with atypical or obscure symptoms and who may be suffering from obstructive CAD, aortic dissection, pulmonary emboli, or other pathologic processes. There is considerable training and practice involved in developing the skills necessary to convert raw information from a CT scanner to optimal diagnostic images; however, MSCT provides important diagnostic information in a faster, less expensive, more patient-friendly, and safer manner than conventional coronary angiography. The following 2 cases describe the use of MSCT coronary angiography in patients with atypical symptoms and exemplify the use of this technology in a clinical setting.
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With the introduction of any new medical technology, debate is required to address issues of optimal and appropriate use. Multi-slice computed tomography (MSCT) coronary angiography is an imaging modality that can identify patients with both soft and hard plaque, supplementing the information gleaned from an ordinary coronary calcium scan and classic risk-factor assessment. Clinicians now have the tools to identify the presence of coronary artery disease (CAD) in the presymptomatic phase, as well as those

needed to help identify the etiology of pain syndromes in patients presenting with atypical or obscure symptoms and who may be suffering from obstructive CAD, aortic dissection, pulmonary emboli, or other pathologic processes. The following 2 cases describe the use of MSCT coronary angiography in patients with atypical symptoms and exemplify the use of this technology in a clinical setting.

CASE 1

A 59-year-old man initially presented at our practice for evaluation 1 year ago, complaining of atypical chest discomfort. At that time, he denied any symptoms of chest pain or shortness of breath with exertion or change in exercise tolerance. His ability to exercise at a high level was seriously limited by chronic osteoarthritis of the knees. He denied any palpitations, paroxysmal nocturnal dyspnea, orthopnea, edema, dizziness, palpitations, syncope, stroke, or claudication. He had no history of myocardial infarction or heart failure and claimed no history of hypertension, smoking, diabetes, or family history of accelerated CAD. On examination, his blood pressure was 130/80 and his pulse was regular at 75 beats per minute. His funduscopic examination was normal. He exhibited normal carotid upstrokes and volume without bruits, normal jugular venous pulsations, and lungs clear to auscultation and percussion. His cardiac exam was normal, with a nondisplaced point of maximum impulse and a regular rate and rhythm, as well as normal S1 and S2 with no murmurs or gallops. His abdomen was soft with no masses or bruits and distal pulses were intact. A 12 lead ECG revealed a regular sinus rhythm with borderline left axis deviation. A non-fasting lipid profile showed total cholesterol of 282 mg/dL, low-density lipoprotein cholesterol (LDL-C) of 153 mg/dL, high-density lipoprotein cholesterol (HDL-C) of 59 mg/dL, and a triglyceride level of 353 mg/dL. He underwent stress nuclear myocardial perfusion imaging, exercising for 8 minutes to achieve a heart rate of 144 bpm (87% maximum predicted heart rate). He had no chest discomfort or significant ST segment depression with exercise and his perfusion imaging was normal. A recommendation was made to modify his diet to lower fat and cholesterol levels, he was started on atorvastatin at 10 mg daily along with baby aspirin, and told to return for another lipid profile in 2 months. At that time, repeat fasting lipid profile showed total cholesterol of 144 mg/dL, LDL-C of 96 mg/dL, HDL-C of 39 mg/dL, and triglyceride levels of 94 mg/dL.

Over the next 11 months, he continued to do well, complaining of only brief twinges of chest discomfort that did not seem related to exertion. Because of his previous elevated cholesterol levels and his concern that he may be afflicted with atherosclerotic CAD, he underwent elective MSCT non-invasive coronary angiography of the chest, to include coronary arteries. In addition to the coronary angiogram, the protocol included data collection for coronary calcium score. The entire chest was included in the scan to assess other possible causes for his pain, such as aortic dissection. The study was performed with a commercially available 16-detector row CT scanner (Somatom® Sensation 16; Siemens Medical Solutions, Malvern, PA) with a scan time of 370 msec, (collimation, 0.75 mm; slice thickness, 1.0 mm; reconstruction increment, 0.5 mm). Cardiac gated images were acquired from the diaphragm to the supraclavicular area. The image was acquired while the patient held an inspired breath for 35 seconds. The patient received a total of 10 mg of intravenous metoprolol to achieve a heart rate below 60 bpm. A total of 120 mL of the iso-osmolar contrast agent iodixanol was continuously injected into an antecubital vein via a 20-gauge catheter with an infusion rate of 3.5 mL/sec. To determine the suitable time for beginning the scan, a region of interest was monitored in the ascending aorta with data acquisition commencing when the signal intensity within the region reached a threshold of 120 Houndesfield Units (HU). Following reconstruction, images were transferred to an InSight workstation (Neo Imagery Technologies, Inc., City of Industry, CA), where maximum intensity projection, volume rendering, and 4D image-reconstruction techniques were used to evaluate 6 phases of the heart cycle.

The total coronary calcium score was only 28 with all of the calcium located in a nonobstructive, complex plaque in the distal left main coronary artery. A score of 28 is well below the 50th percentile for a 59-year-old male and would normally be considered low-risk in the presence of a normal perfusion study. There was no calcium detected in the left anterior descending, circumflex, or right coronary arteries. On review of the reconstructed images, a 90% narrowing of 15 mm in length was found in the proximal left anterior descending artery (LAD) (Figure 1).

This plaque had a mean density of 67 HU, contained no calcium, and was therefore determined to be a soft plaque. There was no significant atherosclerotic disease found in the circumflex or right coronary artery. Due to the severity of the LAD obstruction, the patient underwent conventional coronary angiography 1 week later. Coronary angiography was performed using Cordis 4F JL4 and JR4 diagnostic catheters. The
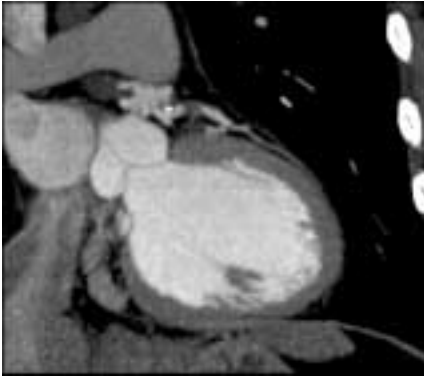
Figure 1. *16-slice CT coronary angiogram showing a severe narrowing in the proximal left anterior descending artery.*

findings on diagnostic coronary angiography confirmed the MSCT coronary angiogram. (Figure 2). A 90% narrowing was identified in the proximal LAD. The plaque originated at the ostium of the LAD and extended past the first septal perforator. Of note was the eccentricity of the plaque, irregular borders, and a small ulcer near the origin, consistent with an unstable plaque. This lesion was flow-limiting at rest, as baseline coronary blood flow was rated TIMI 2.

At this time, it was elected to proceed with revascularization of the LAD and the patient received intravenous heparin to achieve an activated coagulation time between 200 and 300 sec, as well as a bolus infusion

Figure 2. *Conventional coronary angiogram showing a severe narrowing in the proximal left anterior descending artery.*

of abciximab. Using a 6F SL4 guiding catheter and a 014 Trek Balance wire, the lesion was pre-dilated with a 2.5 × 15 mm balloon, resulting in an improved luminal dimension but a residual stenosis of 60%. A 3.0 × 18 mm stent (Cypher;® Cordis Cardiology, Miami Lakes, FL) was placed at 14 atmospheres of pressure, with the proximal aspect of the stent at the origin of the LAD, extending distally to cover the entire plaque. At this time the stent delivery system was removed and an intravascular ultrasound (IVUS) was performed. IVUS revealed good apposition; however, there did seem to be some residual narrowing mid-stent, which responded to dilation with a 3.5 × 15 mm balloon at 11 atmospheres of pressure. The procedure was without complications and the patient was discharged in good condition the following morning on aspirin, clopidogrel, and atorvastatin.

CASE 2

A 45-year-old woman presented to the Emergency Department with severe discomfort and numbness in her left arm. Two weeks of left arm pressure, exacerbated by mental stress and physical activity, were the only symptoms leading to her Emergency Department visit, where a physical examination and ECG were performed as standard procedure. She was told to follow up with her regular physician and scheduled an examination for the following morning. She reported a clear relationship between the arm numbness and intensity of mental stress. She had recently been informed of the presence of peptic ulcer disease and was under treatment with a proton pump inhibitor. Her coronary risk factors included smoking, elevated lipids, and a family history of coronary disease. Her menses cycle remained normal. On physical examination,

blood pressure measured 120/80 with a pulse rate of 86 bpm. Her neck was supple with no bruits; there was no spine tenderness; motor and sensory exam were normal with symmetric reflexes; lungs were clear to auscultation and percussion; cardiac tones were regular in rate and rhythm, with normal S1 and S2 and no murmurs and gallops; abdomen was mildly obese with no masses; distal pulses were intact.
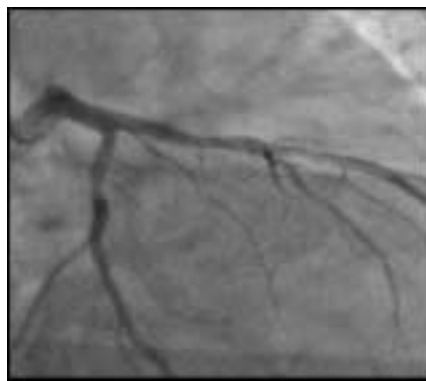
Due to concern over her atypical symptoms related to stress and her multiple risk factors, she underwent a noninvasive CT coronary angiogram utilizing a 64-slice CT scanner (Somatom® Sensation Cardiac 64; Siemens Medical Solutions, Malvern, PA) with a gantry rotation time of 330 msec, (collimation, 0.6 mm; slice thickness, 0.75 mm; reconstruction increment, 0.5 mm). The image was taken while the patient held an inspired breath for 10 seconds. The patient received a total of 20 mg of intravenous metoprolol to lower an initial heart rate of 105 bpm. Rate during image acquisition varied between 65 and 68 beats per minute. A total of 70 mL of the non-ionic contrast agent iohexol was continuously injected into an antecubital vein via a 20-gauge catheter with an infusion rate of 4.5 mL/sec. To determine the suitable time to begin scanning, a bolus of 20 mL was injected and a time/density curve constructed. Six seconds was added to the peak of the time/density curve, to determine the scan delay. Following reconstruction, images were transferred to the InSight work station where maximum intensity projection, volume rendering, and 4D image reconstruction techniques were used to evaluate 6 phases of the heart cycle.

In addition to the coronary angiogram, the protocol included collecting data for coronary calcium score, which was calculated at 2.
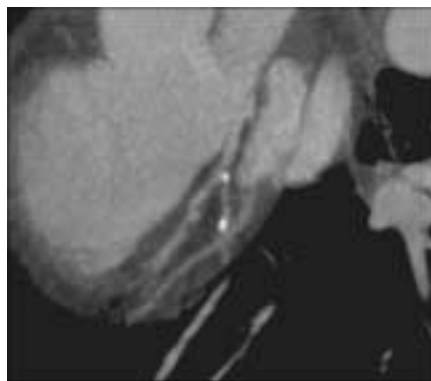
Figure 3. *64-slice CT coronary angiogram showing diffuse disease in the left anterior descending artery with 2 discrete 70% narrowings in the mid left anterior descending artery.*

Figure 4. *Conventional coronary angiogram showing 50% to 60% mid left anterior descending artery stenosis and additional distal narrowing.*

Careful review of the coronary angiogram revealed diffuse non-calcified plaque in the LAD with an estimated 70% stenosis in the mid-LAD (Figure 3). The plaquing observed in the circumflex and right coronary arteries was felt to be mild and non-obstructive. The finding of the anatomically significant obstruction in the LAD led to a functional assessment with a stress myocardial nuclear perfusion examination. The patient exercised for 7:55 minutes on a Bruce protocol to a peak workload of 9.9 METS and reached 83% of her maximum predicted heart rate. Exercise was limited by the development of arm pain. She had a nonischemic ECG response and developed a small,

mild, reversible defect in the anterior wall and apex. Conventional coronary angiography was then recommended. Conventional angiography revealed the presence of extensive plaquing in the LAD, extending from the first diagonal branch to the second septal perforator (Figure 4). The maximal diameter stenosis was estimated at 60%. The first diagonal branch had an 80% to 90% proximal narrowing, in a vessel of about 2 mm in diameter. The patient subsequently underwent IVUS, which measured maximal narrowing at approximately 75% with a luminal area of 2.2 mm^2 (Figure 5). This prompted a revascularization balloon angioplasty of the diagonal branch with a 2 mm balloon, leaving

a 20% residual narrowing, and placement of a 3.0 × 33 mm stent in the diseased segment of the LAD, with no residual narrowing. She was discharged on the following day on aspirin, clopidogrel, and atorvastatin and given instruction on the need for smoking cessation and remains symptom-free.

Discussion

Since 1999, multi-detector spiral computed tomography has been used for the noninvasive detection of CAD. Initial results with 4-detector CT scanning technology was limited by motion artifact, the presence of significant coronary calcium, the need for long breath holds, and less-than-optimal spatial resolution. Reports showed that up to 32% of coronary arteries imaged could not be evaluated. Early studies of 4-slice CT coronary angiography by Achenbach and colleagues[1] showed that of 256 coronary arteries (left main, LAD, left circumflex, and right coronary, including their respective side branches), only 174 could be evaluated (68%). In only 19 patients (30%) could all of the coronary arteries be evaluated. Overall, 32 of 58 high-grade stenoses and occlusions were detected by MSCT (58%). In those arteries that were suitably imaged, 32 of 35 lesions were detected, and the absence of stenosis was correctly identified in 117 of 139 arteries (sensitivity, 91%; specificity, 84%). More recent clinical data describing the ability of 16-detector MSCT coronary angiography have shown a high specificity and sensitivity for the diagnosis of significant CAD. In a recent publication by Kuettner and associates,[2] 58 out of 60 patients had a successful contrast enhanced scan. MSCT correctly assessed 39 of the 40 lesions with greater than 50% obstruction, which were identified by conventional coronary angiography, in patients

Figure 5. *Intravascular ultrasound shows narrowing in the left anterior descending artery to be subocclusive.*

with an Agatston score equivalent (ASE) of < 1000, thus yielding a sensitivity and specificity of 98%. If all patients, including those with high ASEs, were analyzed, the specificity remained high at 97%, and sensitivity at 72%. Similar results were observed by Nieman and coworkers,[3] who demonstrated a sensitivity of 95% and specificity of 86%, and Ropers and colleagues,[4] who reported a sensitivity and specificity of 92% and 93%, respectively, while excluding only 12% of coronary segments because of inadequate image quality. In another report by Kuettner and colleagues,[5] only 6.6% of coronary segments imaged were not interpretable when utilizing 16-slice CT. The correct diagnosis of presence or absence of significant CAD was 90%. The images were acquired using the Sensation 16 Speed 4D (Siemens Medical Solutions, Malvern, PA) with 375 msec gantry rotation. Therefore, 16-slice CT coronary angiography provides significant improvement in scanning efficiency over the 4-slice CT scanners.

From our own experience using both the 16- and 64-slice CT scanners, we have observed an improved ability to obtain coronary artery im-

These scanners have also proved useful in those coronary arteries that are calcified and have had metal stents placed and in patients with faster heart rates.

ages in difficult-to-image patients (the obese, those unable to maintain long breath holds). These scanners have also proved useful in those coronary arteries that are calcified and have had metal stents placed and in patients with faster heart rates. It is clear that non-invasive coronary angiography requires the use of, at minimum, the 16-slice scanner, with improved imaging observed with the 64-slice CT. The pres-

ence of heavy coronary calcification, as observed in the elderly or those with renal failure, does adversely affect the ability to identify and quantitate obstructive disease with a high degree of confidence. However, the presence of calcium scores greater than 1000 does provide diagnostic value in and of itself, identifying patients who may benefit from stress

Identifying disease in the asymptomatic phase, in low- and intermediate-risk patients, allows the targeting of therapies including statins and antiplatelets to secondary prevention goals, resulting in the reduction of coronary ischemic events.

nuclear myocardial perfusion imaging to assist in the detection of obstructive CAD.[6]

Coronary artery bypass grafts are also suitable for imaging with MSCT coronary angiography. Schlosser and associates[7] reported on 54 patients, 3 of whom were excluded from evaluation because of an irregular heart rhythm or rapid heart rate despite β-blockade. A total of 131 bypass grafts (4 internal mammary arteries and 91 venous grafts) were available for evaluation. Of the distal anastomoses, 74% were evaluable, whereas the remaining fraction was limited by

either poor opacification or the presence of surgical clips. All patent arterial grafts were correctly classified, with three quarters of occlusive lesions identified with MSCT. All venous grafts and proximal anastomoses were evaluable. MSCT detected 6 nonocclusive lesions, of which only 1 could be identified by conventional angiography. The ability of MSCT coronary angiography to assist in the identification of asymptomatic,

subocclusive coronary atherosclerosis, above and beyond coronary calcium evaluation, is clear. Identifying disease in the asymptomatic phase, in low- and intermediate-risk patients, allows the targeting of therapies including statins and antiplatelets to secondary prevention goals, resulting in the reduction of coronary ischemic events. It is also clear that MSCT an-

giography has the capability to assist in the detection of obstructive disease in native coronary arteries and bypass grafts.

The limitations of MSCT coronary angiography in evaluating coronary arteries include a reduction of specificity in patients with densely calcified vessels, motion artifact with rapid heart rates, the necessity of iodinated contrast agents to opacify the coronary vasculature, and the need for radiation exposure similar to that received with conventional coronary angiography. There is considerable training and practice involved in developing the skills necessary to convert raw information from a CT scanner to optimal diagnostic images.

The shortcomings of MSCT coronary angiography must be weighed against its advantages as a modality that provides important diagnostic information in a faster, less expensive, more patient-friendly, and safer manner than conventional coronary angiography. In addition, an important benefit of MSCT in the clinical evaluation of chest pain is the ability to evaluate extra-coronary structures including the pulmonary parenchyma and vasculature, the aorta, ventricles, and atria, and other chest structures

that may be the cause of chest pain syndromes, or those structures in which important incidental findings might be made in the screened but asymptomatic patient.

As clinical cardiologists, we are often asked by referring physicians, "does this patient have CAD?" It is not uncommon that patients will undergo stress testing, which we know does not answer this question and can only assess for the presence of hemodynamically significant CAD. Until the advent of CT coronary imaging, we were limited to estimating relative risk of coronary events in patients utilizing the Framingham risk model or by checking levels of coronary calcium or carotid intimal-medial thickness. However, as seen in the above cases, there was a mismatch between the small amount of coronary calcium detected and the degree of coronary artery obstruction caused by a coronary plaque. Therefore, it is clear that a complete examination of the coronary tree, checking for the presence of disease, would mandate the need for contrast angiography to identify soft and calcified plaques. These case reports also confirm the ability of CT coronary angiography to serve as a lifesaving technology.

Our practice has developed protocols that allow for efficient and effective use of cardiovascular imaging modalities. Patients with 1 or more conventional coronary risk factors undergo noninvasive CT coronary angiography. The presence of either a coronary calcium score greater than 1000 or a coronary artery stenosis greater than 50% in diameter signals the need for a physiologic assessment with either stress myocardial nuclear perfusion imaging or stress echocardiography. The decision to perform conventional coronary angiography takes into account all of the clinically relevant information that has now been made available. All patients with the finding of CAD are treated aggressively with medical therapy targeted to their specific risk factor. For patients with atypical symptoms, noninvasive CT coronary angiography is performed as the initial examination. As in the asymptomatic patient population, the presence of an obstruction greater than 50% diameter stenosis or a high coronary calcium score will trigger the need for stress testing. In patients with a normal stress examination, risk factor modification therapies are maximized whereas those with abnormal stress test results will go on to elective conventional coronary angiography. In patients with typical symptoms, noninvasive CT coronary angiography is reserved for those with either a normal or borderline stress test result. CT coronary angiography also provides important information for the interventional cardiologist, including the size of the aorta, the location of aortic plaques that can be sources of peripheral emboli, the identification of an anomalously originating coronary artery, the extent of disease in the left main coronary artery, and the extent of plaque calcium that may affect the strategy for revascularization. A recent publication has shown the advantage of CT imaging to assist the electrophysiologist in obtaining accurate visualization of the pulmonary veins for proper targeting of radiofrequency lesions in patients with atrial fibrillation.[8]

The advent of 16- and 64-slice CT scanners and associated software improvements represents major progress over previous scanning technology to image native coronary arteries and coronary artery bypass grafts and may lead, ultimately, to the replacement of conventional coronary angiography as the gold standard in diagnostic examination. The further advantages of the 64-slice over the 16-slice CT scanners include: 1) thinner slices that allow for more precise measurement of stenosis and visualization of smaller branch vessels; 2) the ability to acquire high quality images in obese patients; 3) CT angiography of

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Main Points

- Multi-slice computed tomography (MSCT) coronary angiography is an imaging modality that can identify patients with both soft and hard plaque, supplementing the information gleaned from an ordinary coronary calcium scan and classic risk-factor assessment.

- Early studies of 4-slice MSCT technology revealed severe limitations in its cardiac imaging capability but more recently introduced 16- and 64-slice systems have obtained levels for sensitivity and specificity in plaque detection of up to 98%, in certain populations.

- Coronary artery bypass grafts are also suitable for imaging with MSCT coronary angiography.

- As with any new technology, work still needs to be done to determine optimal and appropriate use of MSCT, through the careful design and execution of clinical trials.

the heart in only 10 to 12 seconds; 4) a 30% reduction in the volume of contrast media; 5) better characterization of soft plaque; 6) less blooming artifact from arterial calcifications.

We have found CT coronary imaging to be practical in a medium-sized physician group, and that it has certainly changed the paradigm with which we approach the patient at risk for CAD. Application of this technology by cardiologists, particularly those who do not have strong backgrounds in coronary imaging, will require a commitment to the process of training, utilizing standards developed with the assistance of groups who have established expertise. As with any new technology, work still needs to be done to determine optimal and appropriate use. Questions that will need to be answered in carefully designed clinical trials include:

1. Which asymptomatic patients would be candidates for CT coronary angiography?
2. Does screening for CAD and early treatment lead to alteration of the natural course of CAD?
3. How often should scans be repeated?
4. Should asymptomatic patients identified with CAD on CT angiography meet secondary lipid treatment goals?

The above 2 cases represent the ability of the 16- and 64-slice CT scan to perform noninvasive coronary angiography and provide the clinician with important, clinically relevant information above and beyond risk-factor assessment, stress evaluation, and coronary calcium scanning. Both of these patients presented with risk factors for CAD that would not have placed them at high risk, atypical symptoms that were felt to be of a non-coronary cause, and culprit coronary artery lesions that were not calcified and would not have been picked up on a coronary calcium scan. It is clear that noninvasive CT coronary angiography is an important tool for the cardiologists to expedite the diagnosis of potentially life threatening CAD and the initiation of appropriate therapy. ■

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