Priceless Clinical Pearls in the Performance of Cardiac CT

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Cardiovascular CT represents an important innovation in cardiac imaging as a noninvasive modality for the diagnosis of coronary artery disease. As a screening examination, coronary CT has the ability to identify the presence, extent, location, and severity of coronary artery disease in patients at risk. As a diagnostic examination in patients with chest discomfort and dyspnea, it can not only evaluate for the presence of coronary artery disease but also evaluate the pulmonary vasculature and aorta. The ability to perform high-quality cardiac CT requires a combination of technical expertise and knowledge of cardiac anatomy. From our experience having performed over 6000 cardiac CTs, we provide the reader with a number of clinical and technical pearls that will enhance his or her ability to perform high-quality studies even in the more challenging patient.

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The emergence of 64-slice CT scanners and associated software capable of complex 3-dimensional image reconstruction of coronary arteries has revolutionized our approach to patients with cardiovascular disease. Ultrafast CT coronary angiography (CTCA) is capable of providing diagnostic-quality coronary images of soft noncalcified plaque and calcified plaque in the vast majority of patients evaluated with impressive sensitivity and specificity. With spatial resolution of 64-slice CT scanners as low as 0.4 mm, coupled with a positive predictive accuracy above 95% for the presence of coronary artery disease

(CAD), CTCA has emerged as a mainstream technology.[1] This article provides the most comprehensive practical overview of the approach to cardiac and vascular CT-angiography (CTA) based on our experience with over 6000 patients at Westside Medical Imaging (Beverly Hills, CA). We guide you through how to identify the appropriate patients who present for referral for CTCA, review the benefits and risks of CTCA, and share with you the many valuable clinical pearls that we have accumulated by virtue of our extensive experience pioneering this technology.

Screening for Coronary Artery Disease

Why Perform Screening CTCA?

A total of 869,724 Americans died from heart disease in 2004.[2] Heart disease kills more Americans than the 553,000 people who succumb to all cancers combined each year. However, although screening for some cancers (including breast, colon, and prostate) in all risk groups has become the norm and is covered by most third-party payors, there is still resistance from these payors to cover coronary artery screening. It is estimated that 770,000 Americans will have a heart attack in 2008, with an additional 175,000 patients having their first heart attack in 2008. Adverse coronary heart disease mortality trends among young adults (aged 35-54 years), particularly among women, have recently been observed.[3] Despite our best of intentions and the availability of medical therapies such as statins, we fail to identify the presence of disease in at-risk populations in anything close to an adequate fashion, costing thousands of lives each year.

The most commonly applied model for CAD risk assessment is the Framingham risk score (FRS), which was developed in 1948.[4] This model uses a point system for each risk factor, including hypertension, total cholesterol, high-density lipoprotein (HDL) cholesterol, tobacco use, presence of diabetes, and age. The sum of these points is related to future risk of a cardiovascular event. The FRS has come under fire recently for not providing an accurate enough assessment of cardiac risk for a variety of reasons. About 40% of patients in the fifth decade of life who have documented CAD do not have classic risk factors and therefore are mistakenly categorized as low risk by FRS.[5]

A recent analysis of women showed that when FRS was used to assess cardiovascular risk, 95% of women with no pre-existing CAD between the ages of 45 and 79 years were defined as low risk (risk of a cardiovascular event $<$ 10% in 10 years)[6]; 32% of these “low risk” women were found to have coronary calcium, which increased their risk of a cardiovascular event by a factor of 5 over women with no coronary calcium.[7] Consider the hypothetical case of a 50-year-old woman with only 1 major coronary heart disease (CHD) risk factor who, by FRS standards, would be defined as low risk. In actuality, she has a 50% lifetime mortality risk from CHD and an estimated 8-year shorter medial survival compared with a woman with no major CHD risk factors.[8]

In a recently published assessment of coronary risk factors and CAD defined by intravascular ultrasound in the Reversal of Atherosclerosis with Aggressive Lipid Lowering (REVERSAL) study,[9] there seemed to be a disconnect between FRS and CAD burden. In an evaluation of patients presenting with ST-elevation myocardial infarction, unstable angina, or for percutaneous coronary intervention, over 50% of these patients would have been categorized as low risk by FRS.[10] Some of the shortcomings of the FRS may be related to its inability to account for the genetic aspects of cardiovascular disease by not including family history, and the failure to factor in specific low-density lipoprotein (LDL) cholesterol levels or duration of diabetes and smoking. In addition, considering total HDL cholesterol to be protective may be an oversimplification, as some HDL cholesterol molecules are actually proinflammatory and atherogenic.

Two key questions that need to be answered in the debate on the utility and cost effectiveness of screening examinations are 1) whether they lead to changes in patient/physician behavior, and 2) whether these behavior changes lead to a reduction in cardiovascular events. A recent analysis of the effects of carotid intimal-medial thickness (CIMT) screening did show that physicians were more likely to prescribe aspirin and lipid-lowering therapy and apply more stringent LDL cholesterol treatment goals in patients who had abnormal examination results, and that these patients did perceive themselves to be at a higher cardiovascular risk.[11] There were also trends in patients making healthy lifestyle changes as a result of the screening examination. Whether those patients who modify their behavioral risk factors earlier because of the results of a cardiovascular screening examination will be less likely to suffer from a cardiovascular event is an unanswered question. However, one would have to presume until proven otherwise by virtue of the plethora of data assessing cardiovascular risk reduction with lipid lowering therapies that such would be the case. Whether imaging modalities such as CTCA will lead to even more impressive effects is currently under study by our group.

Available Modalities for Cardiovascular Disease Screening

Currently, the most commonly used imaging modalities to help assess cardiovascular risk are coronary artery calcium scoring (CCS), CIMT, and CTCA. CCS and CIMT examinations have been shown to enhance cardiovascular risk assessment by FRS and are simple to perform.[11,12] Recently published data from the MultiEthnic Subclinical Atherosclerosis (MESA) investigators[12] has shown that CCS is a stronger predictor of cardiac events than FRS. The shortcoming of CCS is that it provides no anatomic information, such as whether the coronary artery is located in the key higher-risk proximal locations such as the left main and proximal left anterior descending artery (LAD), or indication of the severity of disease.[13] Anatomy does matter in defining mortality risk in patients with known CAD. Even in the lower-risk group of patients with "low CCS scores" (CCS < 100 in women and CCS < 50 in men), our group has shown that the incidence of hemodynamically significant CAD greater than 50% in asymptomatic patients was nearly 10%.[14] Ultrasound detection of carotid artery plaque is a potent predictor of cardiovascular events.[15] Recent data from our group call into question the sensitivity of CIMT as a screening modality that can define coronary risk.[16] On CTCA, 25% of patients with normal CIMT had hemodynamically significant CAD. The ankle-brachial index is also used to screen for cardiovascular disease. It is easy to perform, inexpensive, and has a high specificity, but is not a sensitive indicator for detecting disease. Stress testing has also been used in the past for disease screening despite the fact that a stress test does not become abnormal until the coronary artery develops a severe stenosis (< 70%).[17] Unfortunately, most coronary artery plaques that rupture and progress to create an acute coronary syndrome occur when they are less than 50% and not identified on a stress test (Figure 1).

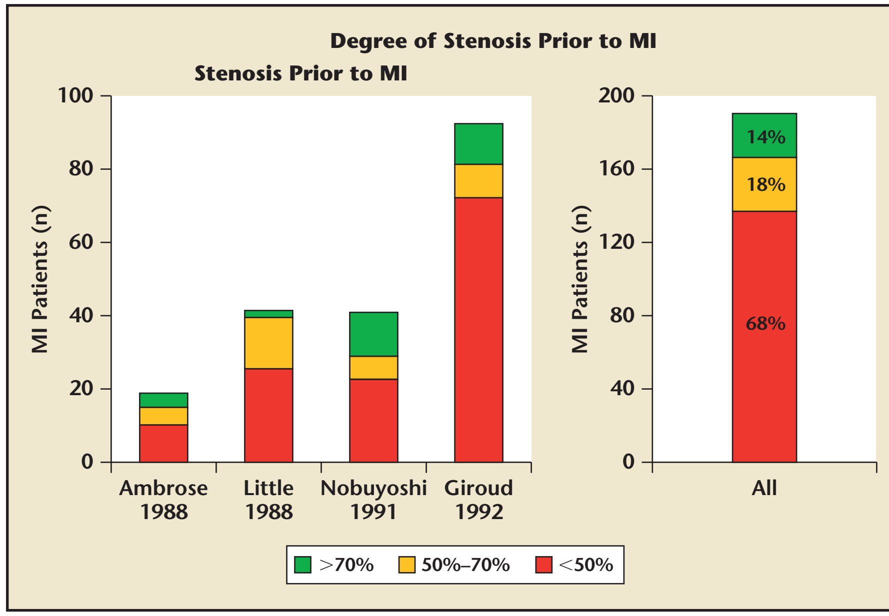

Figure 1. *The majority of coronary artery plaques that rupture and lead to a myocardial infarction (MI) are not occlusive. Adapted with permission from Falk E et al.*[30]

CTCA is the newest noninvasive technology that can provide accurate anatomic information on the location and severity of CAD. There was a high correlation of coronary artery stenosis when compared with intravascular ultrasound and conventional coronary angiography (Figure 2).[18] The advantages of CTCA, in addition to imaging the coronary arteries, include the ability with the same data acquisition to evaluate right and left ventricular function, thoracic aorta and aortic valve anatomy, left atrial thrombi, and pericardial thickening (Table 1).

As we continue to rapidly accumulate clinical experience with CTCA, defining the indications for screening remains a moving target. The most pressing issue for you as a clinician is to determine whether or not your patient has CAD, after which you must approximate his or her risk of experiencing a coronary event. To ascertain this, a good starting point would be to first determine if the patient has CAD, and if he does, then to define his likelihood of experiencing a cardiovascular event. The most effective noninvasive approach to

Figure 2. *Coronary CT angiography showing subtotal noncalcified LAD coronary artery stenosis in patient with acute chest pain and "0" coronary calcium score. LAD, left anterior descending artery; LM, left main artery.*

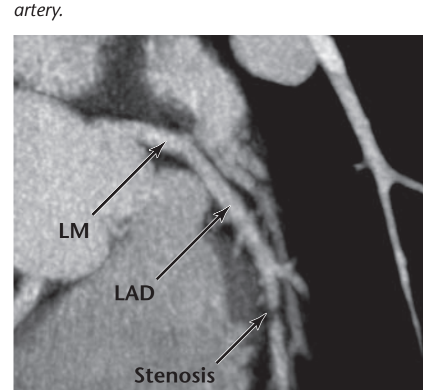

Table 1
Uses of CT in Cardiovascular Disorders

Identify noncalcified and calcified coronary plaque
Semiquantitatively estimate coronary artery stenosis severity
Define anomalous origins of coronary arteries
Evaluate pulmonary vein anatomy prior to and following atrial fibrillation ablation
Evaluate coronary sinus and anterolateral vein anatomy prior to placement of biventricular lead
Identify pericardial effusion and thickening
Identify myocardial infarct (transluminal and subendocardial)
Visualize patency of saphenous vein grafts and arterial bypass conduits
Quantitative assessment of the aortic valve area
Define the anatomy of aortic valves (bicuspid vs tricuspid)
Assess global and regional left and right ventricular function
Identify interarterial communications (atrial septal defects and patent foramen ovale)
Identify left atrial thrombi
Identify cardiac tumors
Identify thoracic aneurysms and dissections

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define the presence or absence of CAD is CTCA. Vulnerability may be related to such factors as plaque composition—which can be assessed by CTCA—or inflammatory and oxidative stress status—which can be assessed with high-sensitivity C-reactive protein, lipoprotein-associated phospholipase A_2, or myeloperoxidase. If the patient does not have CAD, the issue of vulnerability becomes moot. The most recent appropriateness guidelines for CTCA were published in 2006 by the American College of Cardiology Foundation (ACCF)/American College of Radiology (ACR)/Society of Cardiovascular Computed Tomography (SCCT)/Society of Cardiovascular Magnetic Resonance (SCMR)/American Society of Nephrology (ASN)/North American Society for Cardiac Imaging (NASCI)/Society for Cardiovascular Angiography and Interventions (SCAI)/Society of Interventional Radiology (SIR) before there was the depth of clinical experience that we now have with regard to CTCA.[19] Surprisingly, in these guidelines there was no asymptomatic population that was felt to be appropriate for CTCA, even though the majority of the 175,000 Americans who will experience their first myocardial infarction this year come from the lower- and intermediate-risk group as defined by the FRS. An abnormal CTCA outcome in someone from these lower-risk patient groups should result in the patient being treated as high-risk. The recently published Screening for Heart Attack Prevention and Education (SHAPE)[20] classification recommends a proactive approach to "screening all apparently healthy (with no prior diagnosis of CHD) men 45 to 75 years of age and women 55 to 75 years of age who are not considered very low risk."

In our practice, patients who undergo screening CTCA and have severe (> 75%) stenosis of the proximal LAD or greater than 60% stenosis of the left main coronary artery will be triaged to follow-up conventional coronary angiography. All other patients with stenosis greater than 70% in other lower-risk coronary artery segments will be referred for stress testing (preferably to stress echocardiography) to minimize radiation exposure or for nuclear myocardial perfusion stress imaging (MPSI) if acoustic windows are limited or the patient is incapable of exercising. If the stress examination result is abnormal, consideration for referral to conventional angiography is made. All patients, unless there is a contraindication, are started on aspirin and lipid-lowering therapies with a goal LDL cholesterol below 70 mg/dL.

Who Should Have a Diagnostic CTCA?

In the symptomatic patient population, the 2006 ACCF/ACR/SCCT/SCMR/ASN/NASCI/SCAI/SIR guidelines consider a variety of circumstances acceptable for use of CTCA (Table 2). A recent report shows that CTCA in symptomatic patients had sensitivity, specificity, and positive and negative predictive accuracy of 95%, 95%, 75%, and 99%, respectively.[21] In our own clinical practice, the cost saving and efficacy have been shown by significant reductions in referral to the nuclear stress laboratory and for conventional coronary angiography. These findings are consistent with those of Danciu and colleagues,[22] who found that multislice CT (MSCT) was able to identify 80% of a cohort of patients with symptoms suggestive of CAD and intermediate-risk MPSI who were at a low risk of events and in whom conventional coronary angiography could be avoided. The benefit of CTCA does not take into account the enhanced ability to define the cardiac and noncardiac (thoracic aortic aneurysm

Table 2
Guideline-Supported Use of Cardiac CT

Intermediate pretest probability of CAD with an uninterpretable ECG or inability to exercise
Evaluation of suspected coronary anomalies
Evaluation of acute chest pain syndrome when there is intermediate pretest likelihood for CAD, no ECG changes, and serial negative cardiac enzymes
Evaluation of chest pain syndrome with an uninterpretable or equivocal stress test
Evaluation of coronary arteries in patients with new-onset heart failure to assess etiology
Evaluation of cardiac mass in patients with technically limited images from ECHO, MRI, or TEE
Evaluation of pericardial conditions with technically limited images from ECHO, MRI, or TEE
Evaluation of pulmonary vein anatomy prior to invasive radiofrequency ablation for atrial fibrillation
Noninvasive coronary vein mapping prior to placement of biventricular pacemakers
Noninvasive coronary arterial mapping, including internal mammary artery prior to repeat surgical revascularization
Evaluation of suspected aortic dissection or thoracic aortic aneurysm
Evaluation of suspected pulmonary embolism

CAD, coronary artery disease; ECG, electrocardiogram; ECHO, echocardiogram; TEE, transesophageal echocardiogram.

and dissection, pulmonary emboli) causes of chest pain symptoms in an expeditious fashion.

Utility of CTA in Peripheral Arterial Disease

CTCA virtually replaced conventional peripheral angiography for the diagnosis of peripheral vascular disease years ago and the improved resolution of the ultrafast CTA has added a new dimension to the diagnosis and treatment of peripheral arterial disease (PAD). After the confirmation of PAD by ankle-brachial index and/or vascular ultrasound in patients with symptoms of claudication and resting foot pain or nonhealing ulcers, CTA provides a noninvasive arterial luminogram, along with insights into the type of plaque in the vessel wall that can have implications into the selection of devices for revascularization. For instance, the presence or absence of calcium as well as accurate measurement of the vessel size are crucial in planning the nonsurgical treatment of PAD.

The 3-dimensional reconstitution of the peripheral arterial tree that can be performed with CT provides useful information that is unavailable from conventional peripheral angiography. A 360° multiple projection evaluation of peripheral vasculature is readily available using smaller volumes of radiocontrast than the 1-dimensional conventional angiography. Late-phase imaging for identifying the target distal vessels in patients with below-the-knee total occlusions are more accurate and reliable when done by CTA as compared with conventional angiography (Figure 3).

The treatment of carotid obstructive disease has particularly benefited from the information derived from the more advanced ultrafast CT scanning. Plaque composition and

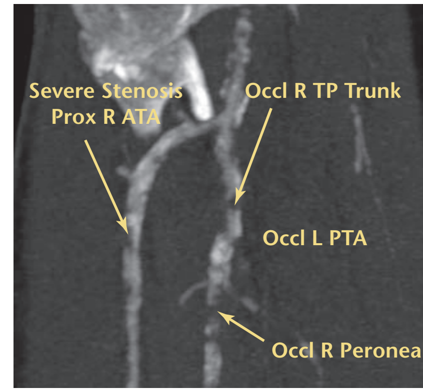
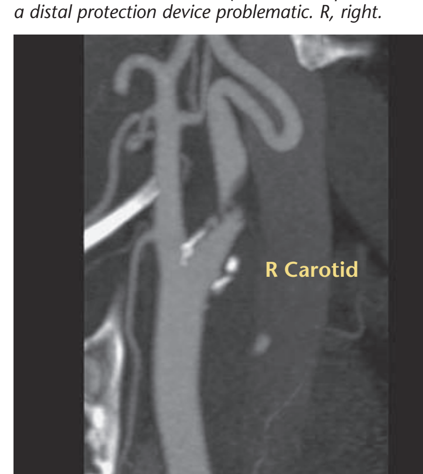


Figure 3. *Lower extremity CT angiography with arterial runoff showing severe disease in the anterior tibial artery (ATA), and occlusive disease in the tibial-peroneal (TP) trunk and peroneal and posterior tibial arteries (PTA). L, left; Occl, occlusion; Prox, proximal; R, right.*

calcification, as well as presence or absence of thrombus, are much better defined by CTA and play an important role in determining whether carotid endarterectomy or carotid artery stenting are the treatment of choice (Figure 4).

CTA plays a key role in developing an approach to stent-graft endoluminal repair of abdominal and thoracic aortic aneurysms. CTA can be used for diagnosis, to provide critically accurate measurements for device siz-

Figure 4. *Carotid CT angiography showing a severely stenotic internal carotid stenosis in a patient who was referred to surgery because of the appearance of calcium and distal tortuosity that made placement of a distal protection device problematic. R, right.*



ing, to assess the iliac artery tortuosity and calcification (which impacts successful device delivery), and to provide short- and long-term follow-up for endoleaks. The unsurpassable resolution of the new generation of MSCT is essential for planning the surgical and nonsurgical treatment of thoracic aortic aneurysms, particularly those that involve the arch and the great vessels.

An evolving use of peripheral CTA is in the early detection of atherosclerosis, which may predate the development of coronary atherosclerosis. Even though the temporal relationship of peripheral arterial atherosclerosis and cardiac and cerebral atherosclerosis is not well defined, the information provided by peripheral CTA may be important in determining the aggressiveness of the treatment for atherosclerosis. Surrogates of atherosclerosis, such as CIMT, have been used for risk stratification of patients with hyperlipidemia.

Imaging Difficult Cases

There are many technical factors to consider when imaging coronary arteries. These are emphasized in courses on cardiac imaging that we teach at Westside Medical Imaging. Radiographic dose is an important consideration, but the most important goal is achieving a diagnostic study. Radiographic dose is analogous to the intensity of a flashlight; below a dose threshold the intensity of light does not allow enough illumination for the production of a diagnostic-quality study. It is important that dose be minimized in younger patients (particularly women under the age of 40 years who have a steady, low heart rate and normal or below normal body mass index), because they are at the highest risk for complications of radiographic exposure. For these patients, the coronary arteries can nearly always be interpreted in the diastolic phase of the heart cycle during diastases. Dose can be reduced by lowering radiation (mAs) during systole and by reducing peak mAs for patients with lower body mass index. Unfortunately this strategy will often result in a nondiagnostic study when attempted in patients with arrhythmias, elderly or obese patients, and in patients with coronary stents or bypass grafts. Achieving a diagnostic study on difficult patients often involves experience-based preplanning, imaging in both systole and diastole, and extensive postprocessing reconstruction strategies that cannot be substituted for by imaging hardware with a greater number of detectors (slices).

Patients With Atrial Fibrillation

Atrial fibrillation (AF) is a common arrhythmia in a cardiology practice. A large segment of these patients will be excluded from being imaged with coronary artery CTA if techniques for imaging are not optimized. Pre-AF ablation pulmonary vein studies frequently include evaluation of the coronary arteries when patients are in AF. When the ventricular response in patients with AF is not controlled it is difficult to obtain a diagnostic-quality study. If the base heart rate can be lowered to less than 80 beats per minute (bpm), and ideally to near 60 bpm, a diagnostic study is most always achievable. In patients with AF it is important to image in both systole and diastole. Frequently, atrial segments that cannot be adequately visualized in diastole will be visible in systole between 20% and 45% of the R-R interval. Bolus timing is important, as the left atrium and left atrial appendage must be well enhanced to allow for observation of thrombus. Close reconstruction intervals of 1% or 2% are required in both systole and diastole to obtain images with minimal motion artifact. The coronary arteries will frequently need to be analyzed by segment as a continuous image from the proximal to distal segment is rarely achieved in a single-phase reconstruction.

Elderly Patients

Even without a prior history of heart disease, elderly patients frequently present with increased coronary artery calcium and some degree of delayed left ventricular relaxation (diastolic dysfunction). Delayed relaxation often results in left ventricular motion throughout the normally imaged portion of the diastolic phase, in which diastasis occurs. Particularly when combined with calcification, this diastolic motion artifact can create a false-positive severe stenosis or obscure the presence of a significant stenosis. Again, imaging during systole and diastole is important as satisfactory images can often be obtained between 25% and 40% of the R-R interval or even in late diastole between 75% and 90% of the R-R interval. Close reconstruction intervals of 1% to 3% are often required, particularly to obtain artifact-free images of the LAD, which is most affected by diastolic dysfunction. Complete cardiac CTA function studies are typically performed on elderly patients.

Patients With Pacemakers

Pacemakers pose multiple challenges when performing cardiac CT imaging. The pacemaker wires themselves cause a metallic artifact on CT that will obscure adjacent structures. This metallic artifact is more of a problem with biventricular pacemakers in which the third wire causes an artifact on left-side coronary arteries as well as the distal right coronary artery/posterior descending coronary artery, which is typically affected by a 2-wire pacemaker. If the patient has a demand pacemaker, it is important to schedule the study so a pacemaker representative can adjust the pacemaker rate to 60 bpm. Once the rate is reset, if the heart rate is too rapid, intravenous β-blockers can be administered until the pacing becomes activated (of course the patient should always be prescreened for contraindications for β-blockers). If the heart is paced and regular during the study, a diagnostic study is frequently obtainable. Reconstruction in both systole and diastole is important. Metallic wire artifact in diastole may obscure a segment of a vessel in diastole but not systole, or vice versa. Also, many pacemaker patients have some degree of either systolic or diastolic heart failure and a slight to significant amount of dyssynchrony can be expected, necessitating 1% to 2% reconstruction intervals.

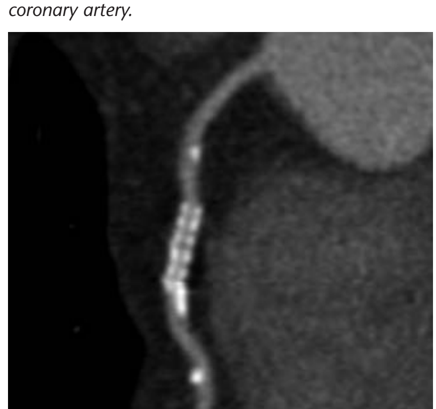
Large Patients

Large patients are a significant challenge because thin slices are required to properly evaluate diseased coronary arteries. Radiographic tubes are limited by the ability to provide the required dose (mAs) to obtain images with an acceptable noise level. When patients approach 300 pounds, have dense upper body musculature, or a large amount of breast tissue, images cannot be properly evaluated. The presence of an elevated heart rate or irregular heart rhythm, stents, or coronary artery calcification further complicates the study. Thicker slices at 1.0 or 1.5 mm may be used to visualize the coronary arteries if calcification is absent or minimal and no stents are present. In younger patients in whom the clinical question is whether the coronary arteries are diseased or healthy, the study can be performed with thick slices and will usually determine if the arteries are healthy or not. Large patients with a complicated cardiac history or known substantial coronary artery calcification are best studied by conventional coronary angiography.

Patients With Stents

Excellent image quality is required to evaluate coronary stents for restenosis or thrombosis. The heart rate should ideally be below 65 bpm with a steady R-R interval. A sharp reconstruction kernel is also required; therefore, patients with a large body habitus are not good candidates for stent evaluation. Dense calcification in the stented segment can also prevent optimal evaluation of a stent. Reconstruction intervals of 1% to 2% are desired in these cases. Typically 5 to 6 images at 1% intervals are viewed as a cine series. At least 2 contiguous phases should show no movement in the stented segment to ensure that any hypodensity seen within the stent or at the proximal and distal ends of the stent is not the result of motion artifact induced beam hardening. Measuring stenosis within a stent is not possible, but hypodensity within the stent is always suspicious for in-stent restenosis. Even with good image quality and no motion, stents that are less than 3.0 mm in diameter can only be evaluated in patients with normal or low body mass index (Figure 5).

Figure 5. *Coronary CT angiography showing no restenosis in the 2.5 mm stent in the mid right coronary artery.*



Coronary Artery Bypass Surgery

Coronary artery bypass graft (CABG) patients typically have at least 1 internal mammary artery graft requiring coverage from the subclavian artery to the apex of the heart. The scanning direction is reversed to caudal-cranial in these patients and a 2-phase bolus is used. It is crucial to have good enhancement in the inferior portion of the heart to evaluate the arteries distal to graft anastomosis. The majority of bypass patients are elderly and there are frequent dysrhythmias and wall motion abnormalities. Pacemakers and automatic implantable cardioverter defibrillators are also frequently present in bypass patients. Ideally, a pacemaker representative should be present to reset the pacemaker to 60 bpm for the study. Evaluation of native vessels typically requires reconstruction in multiple phases of systole and diastole with close reconstruction intervals of 1% to 2%. It is not unusual to find optimal phases for the grafts in diastole and optimal phases for the native vessels in systole (Figure 6). Metallic surgical clips typically will obscure short segments of the graft or the site of anastomosis with the native vessel. Fewer clips are used in recently performed bypass surgeries and do not typically

Figure 6. *Cardiac CT angiography showing patency of the left internal mammary artery and 3 saphenous vein grafts.*

compromise the study. Large numbers of metallic surgical clips often result in a study that is limited to evaluation of graft patency and enhancement in distal native vessels, but not a study that is able to evaluate the grafts for the presence of stenosis or degradation.

Extrasystoles or Heart Rate Instability During Image Acquisition

Both premature contractions and an increase/decrease in heart rate cause a change in stroke volume and thus a spatial change in the position of the coronary arteries. In the case of a premature contraction, a 64-slice–wide volume will be spatially displaced and the affected coronary segment will not be contiguous with the preceding and following coronary artery segments. Multiple premature contractions cause multiple displaced segments. A premature contraction can be manually edited out using the scanner software, but a hazy band remains in the image at the location where the premature contraction is removed. If the coronary arteries are normal or minimally diseased, a premature contraction does not cause the affected segment to be nondiagnostic; however, if the premature contraction occurs in a stented segment or a segment with heavy diffuse calcification, then accurate stenosis evaluation or quantification may not be possible. In the case of a focal stenosis, evaluation in both diastole and systole may solve the problem as a focal stenosis will shift in a cranial caudal direction during the heart cycle and frequently will be clearly seen in either the systolic or diastolic phase.

A steadily increasing or decreasing heart rate that exceeds 8 to 10 bpm from the start to end of the scan causes a continual change in stroke volume, and all 64-slice volume coronary segments will be discontinuous. Normal or minimally diseased coronary arteries may be grossly interpretable by viewing each individual volume segment of the arteries, but a nondiagnostic scan will result in the case of significant diffuse disease.

Minimizing Risk and Maximizing Benefit

As with any other examination that exposes a patient to ionizing radiation ranging from a chest radiograph (CXR) routinely performed as part of an annual physical examination, a nuclear medicine scan, or a CTCA, both the benefits of obtaining the information as well as the risk need to be assessed. The often-used analogy to dissuade against the use of CTCA—*one CTCA radiation exposure is equivalent to 100 CXRs*—may be technically correct; however, the benefit of the information gleaned from 1 CTCA is probably greater than 100 times that obtained from a CXR. Unfortunately, most of the discussions in both the lay and medical press regarding benefit and risk have been unbalanced, focusing mostly on the later.

It is generally accepted in the scientific community that high doses of radiation are linked to both short- and long-term effects.[23] There is no such agreement among scientists with regard to the risk associated with long-term exposure to the types of low-level radiation used in medical diagnostic studies. Examples of certain patient populations that are exposed to higher levels of background radiation either in their living environment or their occupation (eg, airline pilots) have not been found to have increased incidence of cancers.[24,25] The lifetime risk of developing a cancer is not fixed in the general population. Because of the relatively long time it takes for radiographic exposure to induce a cancer (eg, at least 12 years in survivors of the nuclear blast in Hiroshima), younger people who have longer life spans would have a greater lifetime attributable risk (LAR) of developing a cancer. Women are more radiosensitive than men, largely attributed to the radiosensitivity of breast tissue. In a recent analysis estimating cancer risk associated with exposure from a 64-slice CTCA, a 40-year-old woman's LAR was 0.35%, dropping to 0.22% at the age of 60 years, and further to 0.075% at 80 years of age (Figure 7). For men, the LAR of cancer was 0.099% at age 40 years, 0.081% at 60 years, and 0.44% at 80 years of age.[26] These estimates were based on the effective dose of 14 mSv in women and 9 mSv in men using electrocardiographically controlled tube current modulation (ECTCM). At Westside Medical Imaging, instituting low radiation protocols in 2005 in nonobese patients (< 85 kg) by reducing the tube voltage has led to significant reductions in effective radiation doses on top of what is achieved with ECTCM. This protocol is simple to initiate and should not lead to any degradation in the quality of the CT study. Further reductions in radiation dosing may be achieved in the future with prospective gating, which reduces the use of radiographic exposure to one-fifth of the cardiac cycle.[27] SHAPE[20] recommendations for cardiac screening suggest excluding women under 40 years who would have the higher LAR of developing cancer. In the symptomatic patient, the advantage of CTCA over conventional coronary angiography is in being able to avoid the significant vascular risk associated with the later, in particular vascular access site complications.

Contrast Agent Issues With CTCA

The optimal performance of CTCA requires a contrast agent with sufficient

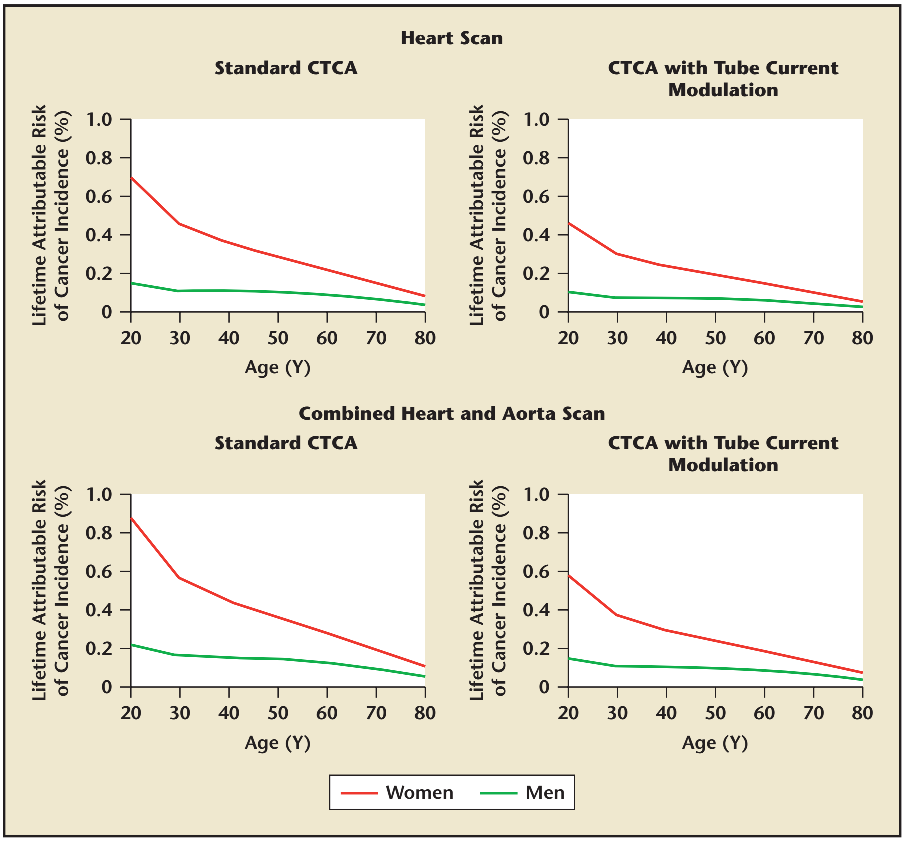


Figure 7. *Illustrates the lifetime attributable risk of cancer incidence from a single cardiac CT coronary angiogram. CTCA, CT coronary angiography. Reprinted with permission from Einstein AJ et al.[26] Copyright © 2007 American Medical Association.*

iodine content to provide adequate contrast between the lumen of the coronary arteries and the artery walls so that noncalcified plaque can be detected (Table 3).

We have been satisfied with the use of iohexol in patients with preserved renal function. In patients with chronic kidney disease (estimated glomerular filtration rate [eGFR] < 50), particularly diabetics, one must exercise caution in order to prevent the development of contrast-induced acute kidney injury (CIAKI). With progressive loss of renal function, the risk of CIAKI increases with the presence of diabetes having a multiplier effect on that risk. Our protocol for CIAKI prevention includes the following for all patients with significant chronic kidney disease:

1. Obtain baseline serum creatinine and blood urea nitrogen (BUN) measurements
2. Hold all diuretic therapy for 24 to 48 hours prior to contrast exposure if patient is not in a volume overload state
3. Intravenous hydration with normal saline (2 mL/kg) for 3 hours prior to CTA and aggressive oral hydration post-procedure for patients for patients with eGFR < 40 mL/min
4. Use of iodixanol as contrast agent of choice with eGFR < 60 mL/min
5. Avoid multiple CT studies requiring additional doses of radiocontrast exposure in the same setting
6. Check serum BUN/creatinine 48 to 72 hours after contrast exposure and compare with baseline level
7. The use of N-acetylcysteine is optional

Table 3
Characteristics of Contrast Media

Compound	mOsm/kg H_2O	Viscosity	Iodine (mg/mL)	Sodium (mEq/L)	gI/kg	LD50 (mouse)
Sodium meglumine	2160	13.3	9.0	370	160	7.5
Diatrizoate meglumine/sodium	1940	10.0	8.4	370	190	7.5
Ioxaglate meglumine/ioxaglate	600	15.7	7.5	320	150	11.2
Iopamidol	796	20.7	9.4	370	2	21.8
Iohexal	844	20.4	10.4	350	5	24.2
Ioversol	702	9.9	5.8	320	2	17
Iodixanol	290	26	11.8	320	19	> 21

Adapted with permission from Brinker J.[33]

Contrast Reactions

Acute allergy-like hypersensitivity reactions occur in 10% to 15% of patients receiving contrast agents and seem to be more common with intravenous administration.[28] Pretreatment with steroids 12 and 2 hours prior to contrast exposure seems to reduce the incidence of hypersensitivity reactions in patients at risk. Late reactions usually occur within 3 days of exposure to contrast but can be delayed for up to 1 week. It is important that both clinicians and patients alike be aware of these late reactions, which can be confused with other conditions. The incidence of delayed reactions seems to be more common in patients with no previous history of radiocontrast exposure, history of allergies, past adverse contrast reactions, and serum creatinine above 2.0 mg/dL.[29] A flu-like syndrome with fever, malaise, arthralgias, and nausea can occur, as well as vomiting, abdominal pain, diarrhea, dizziness. Rare symptoms include wheezing, parotitis, and hypotension. The types of skin reactions vary from the most common measles-like eruptions to erythema multiforme, erythrodermia, eczema, and urticaria. Most delayed reactions are mild and require no specific treatment. If therapy is indicated, symptom-directed treatment with analgesics, antipyretics, and antihistamines is usually sufficient.

Conclusions

Cardiac CT has changed the paradigm for evaluating the patient at risk for developing CAD or symptoms suggestive of a cardiac or vascular disorder. The information from CTCA will often affect the approach of cardiologists in the care of their patients. The shortcomings of FRS to assess cardiac risk increases the importance of imaging to enhance cardiovascular disease risk assessment. To produce optimal CTCA images, the imaging center must be dedicated to the technical aspects of cardiac image reconstruction, which is a labor-intensive process that can at times be tedious. To guarantee the production of high-quality coronary studies, it is imperative that cardiologists who are dedicated to imaging and who have expertise in coronary anatomy and physiology assume leadership roles in the field. ■

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Main Points

- Cardiovascular CT represents an important innovation in cardiac imaging as a noninvasive modality for the diagnosis of coronary artery disease; the emergence of 64-slice CT scanners and associated software capable of complex 3-dimensional image reconstruction of coronary arteries has revolutionized the approach to patients with cardiovascular disease.
- In addition to imaging the coronary arteries, the advantages of CT coronary angiography (CTCA) include the ability with the same data acquisition to evaluate right and left ventricular function, thoracic aorta and aortic valve anatomy, left atrial thrombi, and pericardial thickening.
- The unsurpassable resolution of the new generation of multislice CT is essential for planning the surgical and nonsurgical treatment of thoracic aortic aneurysms, particularly those that involve the arch and the great vessels.
- The optimal performance of CTCA requires a contrast agent with sufficient iodine content to provide adequate contrast between the lumen of the coronary arteries and the artery walls so that noncalcified plaque can be detected.
- The recently published Screening for Heart Attack Prevention and Education classification recommends a proactive approach to screening all apparently healthy (with no prior diagnosis of coronary heart disease) men 45 to 75 years of age and women 55 to 75 years of age who are not considered very low risk.

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