A PHYSICIAN'S GUIDE TO CARDIAC CT

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INTRODUCTION

DESPITE A GROWING UNDERSTANDING of pathophysiology, the stages of progression, the importance of risk-factor assessment for early diagnosis, and the critical role of preventive therapy, coronary artery disease (CAD) remains by far the leading cause of death in the Western world.

Fortunately, recent advances in computed tomography (CT) provide an unparalleled, non-invasive method for evaluating both the wall and the lumen of the coronary arteries. This diagnostic technique not only provides insights into the presence and complications of CAD but, for the first time, offers a non-invasive diagnostic tool that can direct interventional therapy, medical treatment, and lifestyle changes for the medical management of this pervasive disease.

Cardiac CT has become increasingly efficacious in the diagnosis of late stenotic disease and, more importantly, the detection of early CAD with the potential for prevention of acute cardiac events. In response, ProScan Imaging has established the Heart Attack Prevention Institute (HAPI) to focus on this critical and continually evolving role of diagnostic imaging. Our goal is simple and straightforward: To have you and your patients celebrate the golden moments of your families' lives for many years to come. If we help you to attain this goal, our cardiac imaging programs will be an overwhelming success!

This guide provides an overview of cardiac CT, primarily coronary CT angiography (CCTA), as an integral component of the ProScan Institute. We include a brief discussion of recent CT developments that have made an accurate diagnostic evaluation of the coronary arteries a reality. A short summary of radiation dosages from various diagnostic cardiac examinations, as well as our methods of reducing radiation exposure, should answer your questions and the concerns of your patients about this increasingly important and highly publicized topic.

The enclosed Instruction Sheet, Cardiac History Sheet, and Information Sheet are included to outline the CCTA examination from an entirely different perspective – that of your patients being evaluated for possible CAD. Selected illustrations of normal and abnormal studies illustrate the superb anatomic resolution of CCTA, as well as common pathologies and the major diagnostic categories of CAD.

We also have developed algorithms to aid you in navigating the complex and confusing maze of diagnostic tests currently available for the evaluation and subsequent management of patients with suspected CAD. Pertinent references are included to provide you with more detailed information about the rapidly changing field of cardiac diagnostic imaging.

Any decisions regarding the evaluation of possible CAD and treatment of any findings at cardiac CT should be made by you and your patient. Although there is currently no consensus on the precise role of various non-invasive techniques for the diagnosis and follow-up of CAD, we base our clinical indications, algorithms, and patient consultation/discussion information on data in the literature, recommendations by both national radiology and cardiology organizations, and ProScan Imaging's extensive body of clinical cardiac CT experience.

We recognize that excellence is not a destination, but a journey! With that in mind, we welcome and encourage your input and feedback as the indications and applications of cardiac CT continue to evolve. We hope this information is helpful to you and improves the well-being and healthcare of your patients.

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CARDIAC CT: SAVING LIVES EVERY DAY; CHANGING LIFESTYLES EVERY HOUR

COMPUTED TOMOGRAPHY: DYNAMITE, A PRIZE, AND CARDIAC IMAGING

Alfred Nobel (1833-1896), the son of an engineer and inventor, was born in Stockholm, raised in St. Petersburg, and broadly educated in science, poetry, and literature. At the early age of 34, he invented and patented dynamite, a nitroglycerin compound embedded in silica rods that produced a controlled explosion. Nobel amassed a fortune from this invention by building over 90 factories in 20 countries throughout the world for the commercial production and exportation of dynamite.

In Nobel's later reflective years, he became involved in social and peace-related issues. In his last will and testament, Nobel left the bulk of his large fortune to endow annual prizes for excellence in physics, chemistry, physiology or medicine, literature, and peace (Fig. 1). The Nobel Prize in Economics was added later.

In 1901, Wilhelm Conrad Röntgen received the first Nobel Prize in Physics for his "discovery of the remarkable rays subsequently named after him." Godfrey N. Hounsfield, a research engineer at EMI London, and Allan M. Cormack, a professor at Tufts University, later received the Nobel Prize in Medicine in 1979 "for the development of computer-assisted tomography."

Figure 1. Nobel Medal. Cormack and Hounsfield were presented the Nobel Prize in Medicine (Nobel Medal as shown, Nobel Certificate, and monetary award) by King Carl Gustaf XVI of Sweden in 1979 for the development of computed tomography (CT).

Many of us remember EMI London as the original recording and production company of The Beatles. As we look back almost 30 years, it could be said that computed tomography (CT), one of the most powerful tools of the medical specialty of Diagnostic Radiology, evolved from space-age technology of the Sputnik Era that was conjointly refined by a brilliant scientist with a "research and development grant" funded at least in part from the enormous profits generated for EMI by a rock group!

Since the initial clinical applications of CT in 1972 by radiologists, this diagnostic modality has profoundly affected patient care. By 1981, approximately 3 million CT examinations were performed in the U.S. This annual volume continued to grow dramatically, to 34.9 million in 2000 and 62.8 million in 2005 [1], further evidence of its utility and medical efficacy. CT has become critical for evaluating the central nervous system, head and neck, spine, musculoskeletal system, chest, abdomen, and pelvis. However, because of the rapid motion of the heart, CT's cardiac applications remained limited until the early 2000s.

The recent revolution in CT technology now allows precise imaging of the heart and coronary vessels. Cardiac CT entered "prime time" in Cincinnati in early 2005, with the installation of a high-definition, multi-detector CT scanner at ProScan Imaging's Midtown location. By this time, CT scan times had become rapid enough to virtually "stop the heart in motion."

The introduction of multi-detector CT, EKG-synchronized scanning, and reconstruction techniques permit rapid sections of the entire heart without the loss of anatomic detail. For example, the Philips 64-detector CT at ProScan Midtown, where our cardiac CT examinations are performed, has a temporal resolution of 165 milliseconds. This means that each CT section is obtained during this time; only motion that occurs during this ultra-short time span (16/100ths of a second) will appear blurred. Since EKG-modulation directs CT sections to be obtained during cardiac diastole, when the heart is relatively motionless, the heart appears to be "stopped" (Fig. 2).

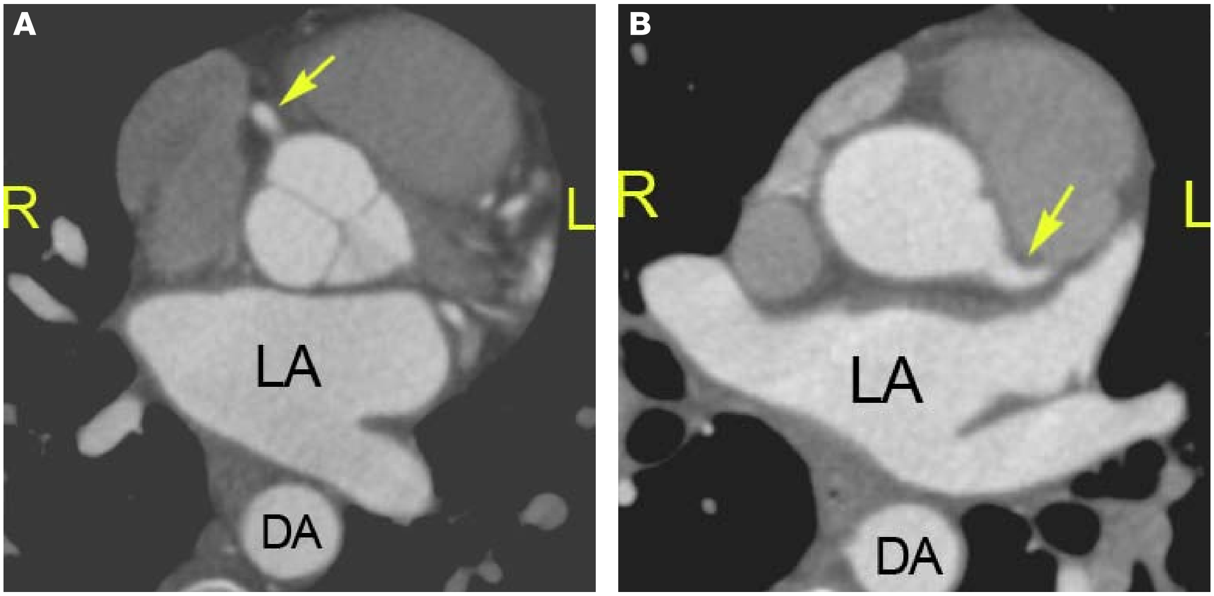

Figure 2. Normal Origins of the Coronary Arteries. Axial CCTA section at the level of the aortic valve. [A] The right coronary artery (arrow) originates anteriorly from the right coronary cusp. [B] The left coronary artery originates posterior and lateral (arrow) from the left coronary cusp. LA – Left Atrium; DA – Descending Aorta; R – Right; L – Left.

Despite these rapid scan times, the spatial resolution of the Philips 64-slice CT is still 0.4 millimeters. This measurement of detail indicates that linear densities only fractions of a millimeter apart can be distinguished as separate structures. As a result, the lumen and walls of the major coronary arteries (3-5 millimeters in diameter) and even their branches (1-3 millimeters in diameter) (Fig. 2) are readily visualized.

CARDIAC CT RADIATION DOSE: HOW MUCH IS TOO MUCH?

Radiation exposure during cardiac CT examinations, especially CCTA, has recently received heightened attention in the medical literature [4] and the general media. This is due not only to its current and potentially expanding role in the early diagnosis of CAD [2], but also to confusion about appropriate indications for the various diagnostic examinations and their radiation exposures.

ProScan Imaging feels that concerns about any radiation exposure are always justified; we are strong proponents of the ALARA (As Low As Reasonably Achievable) principle. We use many methods to reduce radiation exposure during cardiac CT examinations. Moreover, patients and their referring physicians should expect similar concern and awareness of radiation exposure with the performance of all imaging examinations. Some of our radiation reduction methods include education and radiation concern of all imaging personnel, appropriate patient selection, breast shielding of all female patients, therapeutic heart-rate control, individualized CT technique, accurate dosage monitoring, and meticulous dosage data collection.

In our view, the most important component in any effort to decrease radiation exposure is the creation of an atmosphere of awareness and an emphasis on exposure reduction. Patients and their referring physicians should be informed of the radiation exposure from CT and all imaging examinations (Table 1); any exposure must always be weighed against the potential positive medical benefit. Technologists should consider radiation exposure on a personal basis, because radiation of any patient, particularly younger patients, exposes the genetic pool of the entire population to induced risk.

Again, appropriate patient selection must be emphasized. For example, a recent article pointed out the potential increased future risks of breast cancer from CCTA in 20-year-old females [4]. We do not dispute the medical evidence presented by the authors, but simply state that CCTA is rarely, if ever, indicated in this young population.

Table 1 provides a list of select radiation dosages. It should be noted that the average annual background radiation exposure (normal exposure primarily received from the sun and the soil) is approximately 3.6 milliSieverts (mSev), depending on location in the U.S.; the normal background exposure is greater at higher altitudes. The usual retrospective, EKG-modulated CCTA examination performed at ProScan Imaging has a radiation dose comparable to that of a chest CT and less than that of a "low-dose" nuclear medicine stress test. Moreover, the dosage from prospective CCTA, which can now be performed in the majority of patients, is slightly less than the average annual background radiation exposure (Table 1).

IMAGING OF THE CORONARY ARTERIES: WHO AND HOW?

There are myriad imaging techniques, invasive and non-invasive, available for diagnosing abnormalities of the coronary arteries and the effects of these abnormalities. The selection of patients for evaluation (Who?) and the appropriate modality for this assessment (How?) is both complex and confusing. Although precise guidelines are being evaluated by large, ongoing clinical trials, contrast-enhanced coronary CT angiography (CCTA) currently best fulfills the requirements for non-invasive morphologic assessment of the coronary arteries. This is due to its combination of unprecedented rapid acquisition speed, exquisite spatial resolution, and robustness of information [11-13].

INDICATIONS

The indications for imaging of the coronary vessels, primarily the coronary arteries, are listed in Table 2 [2, 6, 11-13]. Some of the less frequent indications include abnormalities of the anatomy or origin of the coronary arteries (Fig. 3), assessment of patency of bypass grafts (Fig. 4), evaluation of coronary artery stents (Fig. 5), and imaging of the coronary arteries prior to surgical or interventional therapy. However, the most common and certainly most important indication for coronary vascular imaging is the diagnosis

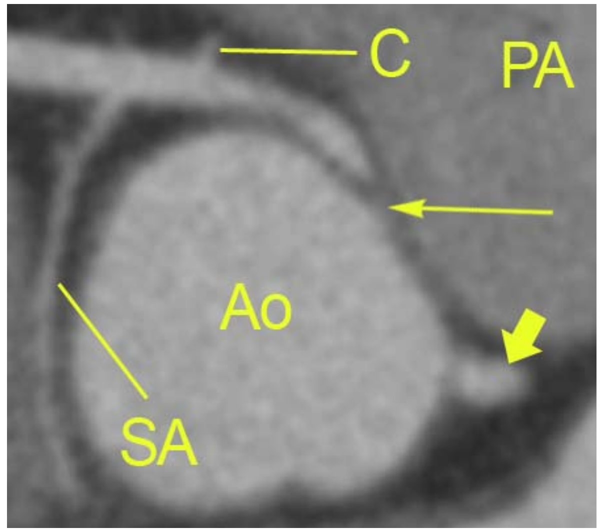

Figure 3. Aberrant Origin of the Right Coronary Artery – "Malignant" Type. Axial CCTA section at the level of the aortic valve. The origin of the left coronary artery (short arrow) is in normal location. However, the right coronary artery also originates from the left coronary cusp (long arrow). As a result, the right coronary artery courses between the aorta (Ao) and pulmonary artery (PA); this may lead to cardiac ischemia during exercise. Note the excellent resolution of the 1mm-diameter conus (C) and sinoatrial node (SA) branches of the right coronary artery.

Table 1. Effective Radiation Dosage, Measured in MilliSieverts (mSv)[1,10]

Average Background Dose – U.S.	3.6 mSv/year
Three-Hour Commercial Airline Flight	0.015 mSv
Pa & Lateral Chest X-Ray	0.05 mSv
Head Ct Examination	1-2 mSv
Chest CT	5-7 mSv
Abdomen & Pelvis CT	6-8 mSv
Selective Diagnostic Coronary Angiography	3-6 mSv
Diagnostic Coronary Angiography with Intervention	6-30 mSv
Nuclear Medicine Stress Test	
SPECT Thallium	25.3 mSv
SPECT Sestamibi	12.2 mSv
Coronary CT Angiography	
Retrospective CCTA	13 mSv
Retrospective EKG-Modulated CCTA	8-9 mSv
Prospective "Step-and-Shoot" CCTA	2-3 mSv

TABLE 2. INDICATIONS FOR IMAGING OF CORONARY VESSELS [2, 6, 11-13]

- **Abnormal Coronary Vessels**
  - – Collateral Vessels
  - – Vascular Anomalies
  - – Aberrant Origin of Coronary Arteries
- **Bypass Graft Patency**
  - – Arterial
  - – Venous
- **Coronary Artery Stent Evaluation**
  - – Patency
  - – In-Stent Restenosis
- **Pre-Operative Evaluation of Vascular Anatomy**
  - – Cardiac Surgery
  - – Surgery of Great Vessels
    - Aorta
    - Pulmonary Artery
  - – Non-Cardiac Surgery
  - – Vascular Ablation
- **Coronary Atherosclerosis/Coronary Artery Disease (CAD)**
  - – Diagnosis
    - Replace Initial Diagnostic Stress Test
    - Clarify Equivocal Stress Test
    - Positive CT Calcium Score (CTCS)
    - Replace Elective Conventional Coronary Angiography
  - – Coronary Artery Atherosclerotic Plaque
    - Characterize: Lipid; Fibrous; Calcified
    - Plaque Burden
      - – Vessels Involved
      - – Amount of Plaque: Mild; Moderate; Severe
  - – Disease: Negative; Minimal; Mild; Moderate; Severe
  - – Management: No Treatment; Conservative; Interventional; Surgery
  - – Treatment Follow-Up

and assessment of severity of coronary artery disease (Table 2).

Our understanding of the epidemiology, prevalence, and pathophysiology of CAD has increased dramatically over the past three decades. The importance of age, sex, family history, diet, lifestyle, serum lipids, blood pressure, and diabetes in the development and progression of this most common of all diseases is now well known. The algorithm for the imaging diagnosis of CAD (Fig. 6) is based on recommendations by the American College of Cardiology Foundation and the American College of Radiology [6], with modifications by ProScan Imaging based on our clinical experience and an updated literature review.

It should be noted that only low-risk patients– defined as either having no classic risk factors (metabolic syndrome, hypertension, elevated cholesterol, cigarette smoking, positive immediate family history, diabetes) and females below age 55 or males below age 45 – <u>should not</u> have screening for CAD by CT calcium score (CTCS) (Fig. 6). Moreover, we recommend CCTA for any patient with a positive (>0) calcium score (Fig. 6).

Because of its lower radiation dose, greater anatomic information, increased sensitivity and specificity, and usefulness in patient management, CCTA has replaced the nuclear medicine stress test as a primary imaging modality in the diagnostic algorithm for CAD (Fig. 6). However, the nuclear medicine stress test is a critical supplementary study for assessing the functional significance of a segment of moderate coronary artery narrowing identified at CCTA in the asymptomatic patient (Fig. 7). Any patient with symptoms or other indications of an acute coronary event should be referred directly to a cardiologist for conventional angiography and possible interventional therapy or surgery; no additional non-invasive imaging is indicated.

IMAGING TECHNIQUES

Conventional Coronary Angiography, for many years considered the standard for the detection of CAD due to its unsurpassed spatial resolution, displays only the vessel lumen (the "doughnut hole") and the

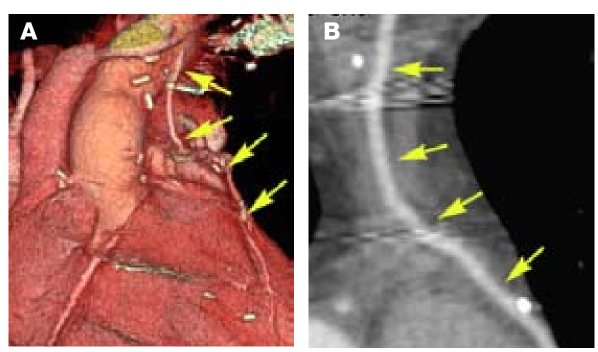

Figure 4. Patent LIMA Vascular Graft. [A] A 3D volume-rendered CCTA image demonstrates a left internal mammary artery (LIMA) graft (arrows) extending from the aorta (upper arrow) to the left anterior descending coronary artery (lower arrow). [B] Subsequent coronal multiplanar reformatted image verifies that the LIMA graft is widely patent (arrows).

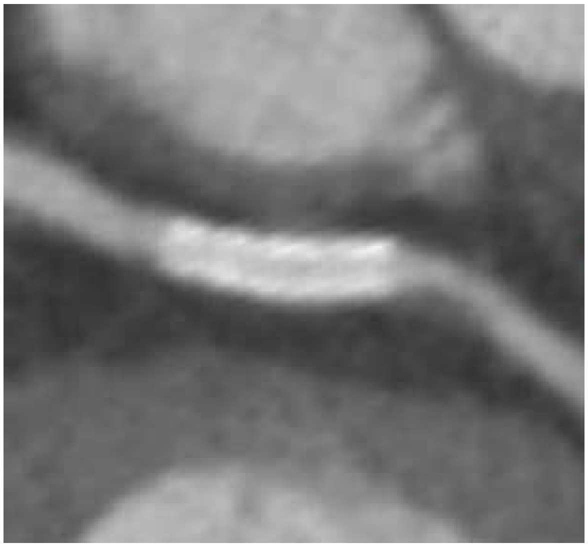

Figure 5. Patent Circumflex Coronary Artery Stent. The stent is completely deployed, covers the lesion, and shows no evidence of in-stent restenosis.

degree of luminal narrowing (stenosis) by showing the inside of the vessel like a cast molding of a tube [12]. It fails to show the coronary artery wall (the "doughnut"), which is known to be the site of the earliest changes of CAD. Moreover, coronary angiography is invasive and extremely expensive. However, since interventional therapy can be performed at the time of selective angiography, it is recommended in patients with evidence of an acute coronary event, severe CAD by CCTA, moderate CAD at CCTA in the symptomatic patient, and asymptomatic patients with moderate CAD at CCTA and a positive stress test (Fig. 7).

Intravascular Ultrasonography, performed in conjunction with conventional coronary angiography, is able to accurately characterize coronary arterial wall lesions. This examination is also invasive and expensive.

The Nuclear Medicine Stress Test indirectly determines the presence or absence of coronary artery disease by assessing cardiac perfusion. Like all nuclear medicine examinations, it is an indicator of function and does not demonstrate anatomy; there is no morphologic assessment of the coronary arteries. The stress test cannot identify plaque or assess plaque burden. Hence, it neither contributes to risk stratification if there is no functional coronary stenosis, nor does it aid in future conservative patient management. In addition, a positive stress test requires a 65% to 70% coronary artery stenosis; this extent of vessel narrowing occurs only in very severe CAD. Despite these shortcomings, the nuclear medicine stress test, as discussed previously, is valuable in the asymptomatic patient with moderate changes of CAD at CCTA. If the subsequent stress test is negative, counseling and conservative treatment should be considered; if the stress test is positive, conventional coronary angiography is recommended (Fig. 7).

The CT Calcium Score (CTCS) is a method for the detection and quantification of coronary artery calcium, in which non-enhanced CT sections are obtained through the heart. Since arterial calcifica-

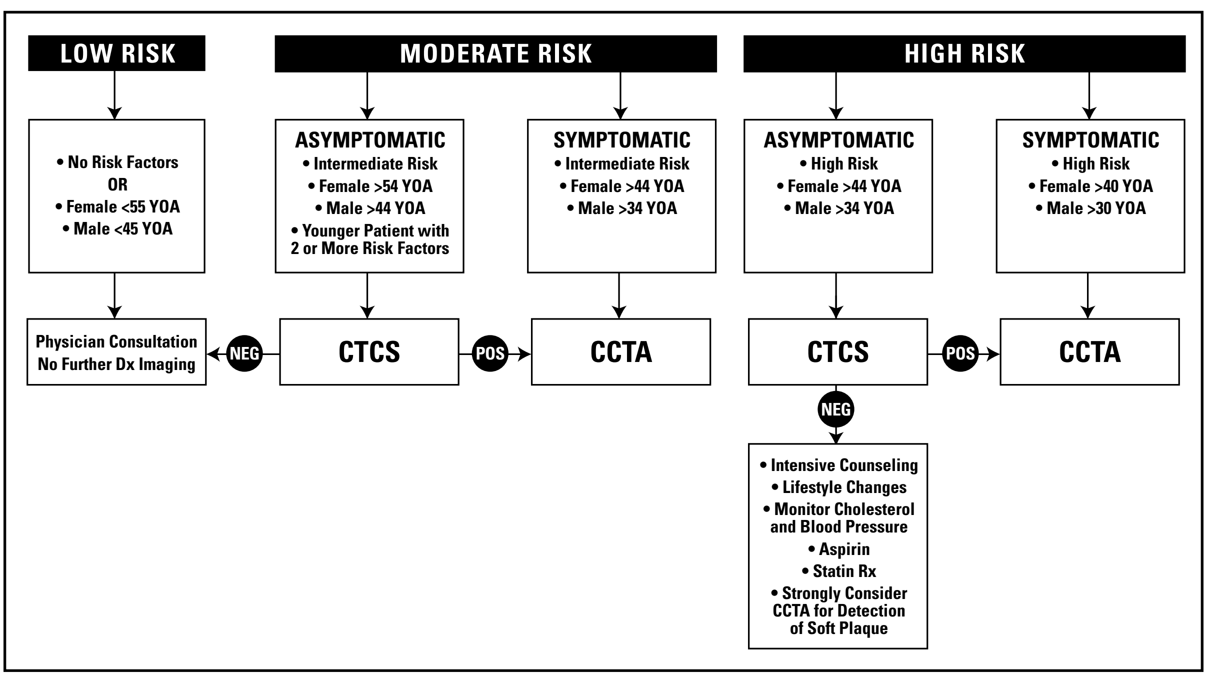

Figure 6. Algorithm for Diagnostic Evaluation of Coronary Artery Disease (CAD).

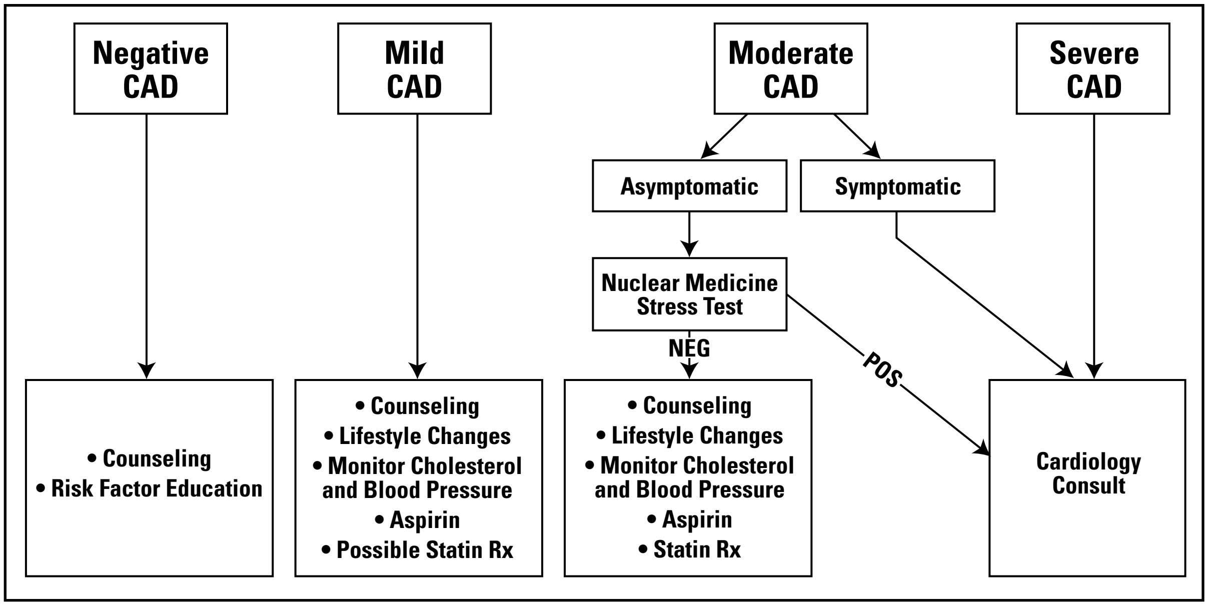

Figure 7. Algorithm of CAD Categories at CCTA, with Management Recommendations.

tion is almost always due to atherosclerosis, detection of coronary artery calcium is a highly sensitive, non-invasive tool for determining the presence of CAD. Moreover, the absence of coronary artery calcification at CT has a high negative predictive value for ruling out the presence of atherosclerosis, and thus stenotic CAD. The advantages of CTCS are the lower radiation dose (1 mSv), lower cost, and ability to perform without intravenous contrast material. However, CTCS is unable to identify non-calcified (lipid, fibrous) plaque. Moreover, calcification of plaque occurs during the more advanced stages of vascular remodeling and healing of coronary atherosclerosis.

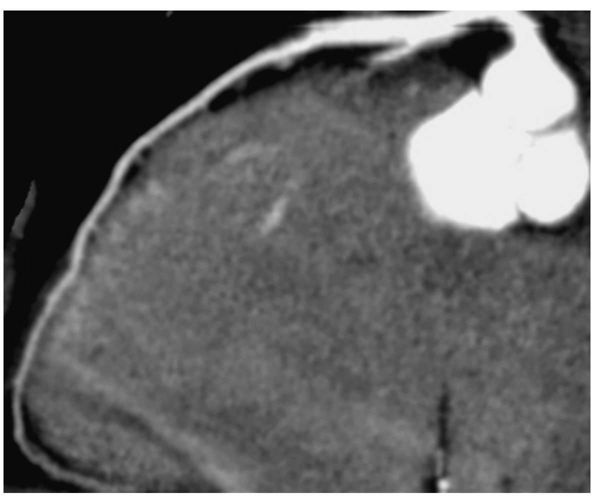

Figure 8. Normal Left Anterior Descending Artery (LAD). Curved multiplanar reformation in oblique anterior coronal orientation from CCTA demonstrates a normal LAD.

This explains the finding that acute coronary syndromes are usually associated with lesser amounts of coronary calcium, while the presence of more extensive calcification is characteristic of more stable CAD [7]. Moreover, some patients with critical vessel narrowing by soft plaque will have a calcium score of zero.

Coronary CT Angiography (CCTA) has revolutionized imaging of the coronary arteries. It is able to visualize not only the lumen (the "doughnut hole") but also the wall (the "doughnut") of the coronary arteries. Since atherosclerosis begins in the wall of the coronary vessels, CCTA is the only non-invasive technique that is able to detect the earliest changes of CAD!

CAD, starting as plaque deposition in the arterial wall, progresses over many years. Although atherosclerotic plaques may develop in anyone, they are particularly likely to develop in the "vulnerable patient": one with high serum total cholesterol; a high ratio of total cholesterol to HDL; and elevated levels of C-reactive protein.

The concept of "vulnerability" also applies to atherosclerotic plaque, non-invasively characterized by CCTA [5]. These "vulnerable plaques" are more likely to rupture with subsequent complications of thrombosis, occlusion, and acute cardiac events such as myocardial ischemia or infarction. Vulnerable plaque demonstrates compensatory enlargement of the involved segment ("positive remodeling"), a larger area, an eccentric lumen, less than 50% stenosis, a thin fibrous cap, and a necrotic, lipid-rich, macrophage-rich core[5-8]. The vessel lumen adja-

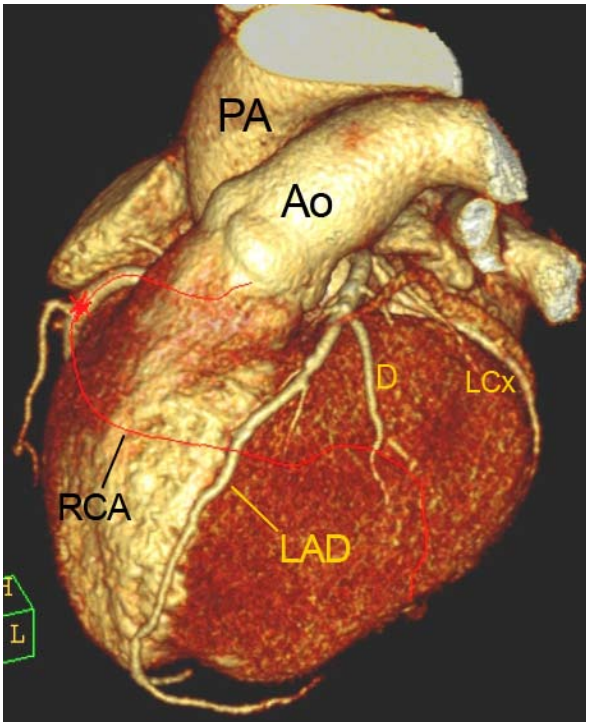

Figure 9. Normal Color Volume-Rendered View of the Heart from LAO Perspective. The left anterior descending coronary artery (LAD) extends around the apex of the heart and has a large diagonal branch (D). The red computer tracking line indicates the posterior extent of the dominant right coronary artery (RCA). The circumflex coronary artery (LCx) is of moderate size. This view is used primarily to illustrate the capabilities of CCTA to patients; it may be extremely helpful to sort out the position of vascular grafts for subsequent analysis (See Fig. 4). Ao – Aorta; PA – Pulmonary Artery.

cent to a vulnerable or ruptured plaque may have a completely normal diameter without evidence of stenosis – findings invisible at conventional coronary angiography but readily apparent at CCTA [12]!

Atherosclerotic plaque contains lipid particles, cholesterol crystals, macrophages, foam cells, cellular debris, smooth muscle cells, and an elastin-collagen fibrous cap. CCTA is able to characterize plaque as primarily lipid (~ 50 HU), fibrotic (80-90 HU), or calcific (> 400 HU) (See Fig. 13). Moreover, the presence of positive remodeling (expansion of vessel wall at plaque site to 1.1 times normal) or negative remodeling (local shrinkage of vessel size) are readily identified.

Finally, CCTA's multiplanar reconstruction capabilities allow complete visualization of the major branches and segments of the coronary artery circulation with a high degree of accuracy (sensitivity – 94%; specificity – 97%; PPV – 87%; NPV – 99%) [9]. Vessels visualized on a CCTA examination include the right coronary artery (proximal, mid-portion, distal) and its branches (posterior descending artery, posterolateral ventricular), left main coronary artery, left anterior descending coronary artery (proximal, mid-portion, distal) and its branches (diagonal 1, diagonal 2), circumflex coronary artery (proximal, distal) and its branches (oblique 1, oblique 2), and ramus intermedius, if present.

Because of this combination of individual vessel and global coronary circulation analysis, CCTA is able to assess plaque burden. Although such analysis is in its infancy, a measure of plaque type (soft, hard) and extent (mild, moderate, severe) within each of the 15 or 16 coronary artery segments provides an indication of total plaque burden. This should be helpful in the future for risk assessment, disease management, and treatment follow-up.

CCTA DIAGNOSTIC CATEGORIES: AN AID TO DISEASE MANAGEMENT

Until cardiac CT became clinically feasible for evaluating the coronary arteries, there was no non-invasive diagnostic examination to aid in the conservative, medical management of CAD. This is the rationale

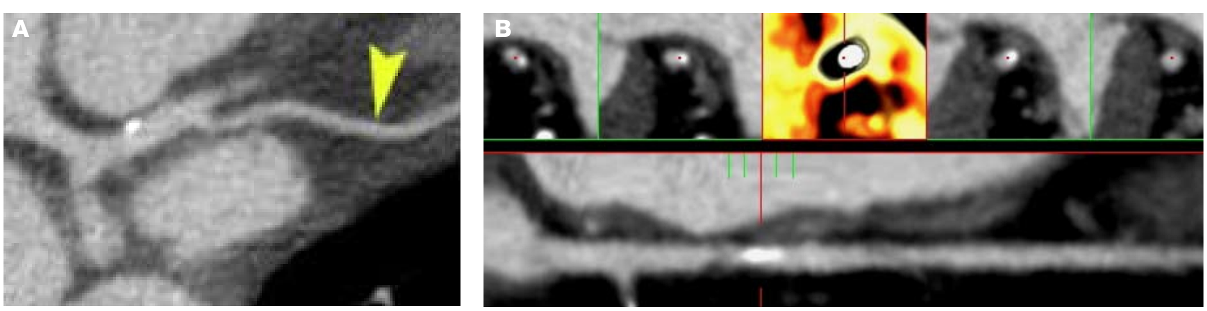

Figure 10. Mild CAD. [A] Minimal Disease. Axial CCTA section through bifurcation of left main coronary artery. A punctate, calcified atherosclerotic plaque is visualized in the proximal LAD ("the widowmaker" position). All vessels are widely patent without evidence of stenosis. Note the large diagonal branch of the LAD (arrow). [B] Mild Disease. Multiplanar reformation with linear (below) and cross-sectional (above) display along an automatically generated centerline shows a calcified plaque in the LCx. The color cross-sectional display above ("Virtual Intravascular Ultrasound") confirms that the hard plaque fills less than 50% of the vessel lumen.

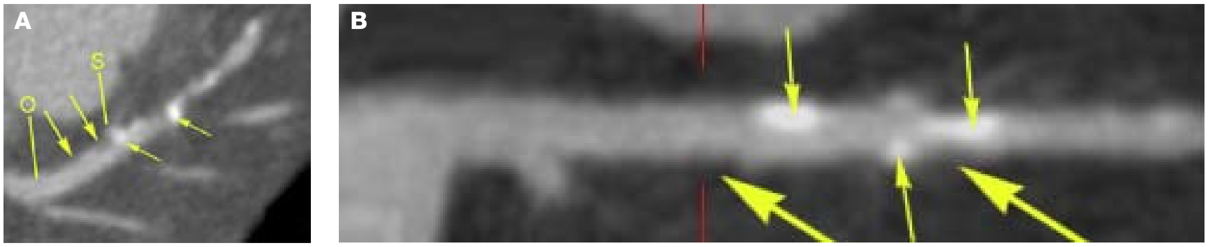

Figure 11. Moderate CAD. Axial [A] and linear [B] multiplanar reconstructions (MPR) demonstrate between 50% and 70% narrowing of the LAD by soft (large arrows) and hard (small arrows) plaque. The critical "widowmaker" position is between the origin (O) and the first septal perforator (S) of the LAD. Since this patient was asymptomatic, nuclear medicine stress testing was performed to assess the functional significance of this moderate CAD.

for CTCS becoming the current screening modality of choice for CAD: It is relatively inexpensive (< $100), relatively low in radiation dosage (1 mSv), and widely available. However, as techniques improve, radiation protection measures improve, radiation dosage decreases, and costs decrease, the case for CCTA to replace CTCS as the screening technique for CAD becomes stronger and stronger [2]! At this time, many patients and their referring physicians are certain to make a conscious decision to obtain CCTA as the definitive examination for the diagnosis or exclusion of CAD, rather than rely on calcium scoring.

Diagnostic categories of CAD can now be defined by CCTA (Fig. 7). Each study is assessed for the presence of plaque, the extent of plaque burden, and the degree of wall remodeling. If plaque is identified, it is characterized as hard or soft by CT density in Hounsfield units (HU). Individual categories of diagnosis indicate compromise of coronary artery lumen caliber, with 50% and 70% being extremely important degrees of stenosis. The percentage of stenosis for the left main coronary artery to be categorized as moderate or severe disease is lower than narrowing in other vessels.

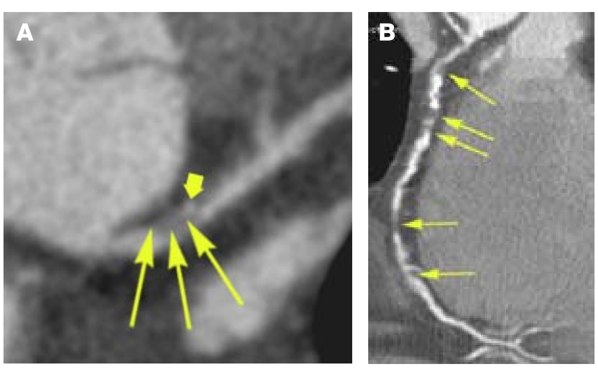

Figure 12. Severe CAD. [A] Axial CCTA shows large focus of soft plaque (long arrows) in the proximal LAD that contains a small peripheral focus of hard plaque (short arrow). The vessel lumen in this "widowmaker" position is over 70% occluded. The patient was referred to a cardiologist for emergency conventional coronary angiography. [B] Sagittal MPR section of the RCA. There are multiple soft plaques in the RCA (arrows) producing >70% stenosis. The patient underwent bypass surgery.

The algorithm in Figure 7 includes four diagnostic categories (Negative, Mild, Moderate, Severe) of CAD. It must be emphasized that any treatment decisions should be made by the referring physician in consultation with the patient. This critical point is underscored as the attending radiologist at ProScan Imaging discusses the CCTA examination with the patient and describes potential treatment options. A review of images and discussion with the patient immediately after completion of the cardiac CT examination dramatically improves compliance with any subsequent conservative or medical therapy [7].

Summary diagnostic impressions and potential treatment options are diagrammatically shown in the algorithm in Figure 7. A negative CCTA demonstrates no CT changes of CAD in the wall or lumen of the coronary arteries. There is no hard plaque, soft plaque, or coronary artery stenosis (See Figs. 2, 8, 9). It is appropriate for the patient, even with a normal CCTA examination, to discuss risk factor assessment with his or her physician (See Fig.7). Approximately one-third of patients in an outpatient setting have negative CCTA examinations [3].

The spectrum of mild CAD is very broad; it includes those patients who have soft or hard plaque without any stenosis (minimal disease), as well as those with plaque formation and stenosis of as much as 50% (See Fig. 7). In most large outpatient settings, this category accounts for just over half of all CCTA patients [3]. Treatment is based on the severity of disease within this category: If minimal (Fig. 10A), conservative measures are usually effective. If the patient with mild CAD has more plaque formation (Fig. 10B), especially soft plaque, or some stenosis, then intensive counseling with lifestyle change, aspirin therapy, and statin treatment should be considered (See Fig.7).

Moderate CAD is characterized by the presence of soft or hard plaque and coronary artery stenosis of between 50-70% (Fig. 11); again, a narrowing of 40% to 50% in the left main coronary artery is considered moderate CAD. If asymptomatic, the patient with moderate CAD should have a nuclear medicine stress test (See Fig. 7). If this examination is negative, appropriate treatment is counseling, lifestyle change, aspirin, and statin therapy. If the stress test is positive in an asymptomatic patient with moderate CAD or if a patient with moderate CAD has symptoms, a cardiology consultation should be obtained (See Fig. 7).

Finally, severe CAD by CCTA is soft or hard plaque with vessel narrowing (stenosis) of 70% or greater (See Figs. 12, 13). A 50% narrowing or greater of the left main coronary artery is considered severe CAD. Any patient with severe CAD should be referred to a cardiologist for angiography and possible interventional therapy or surgery (See Fig. 7).

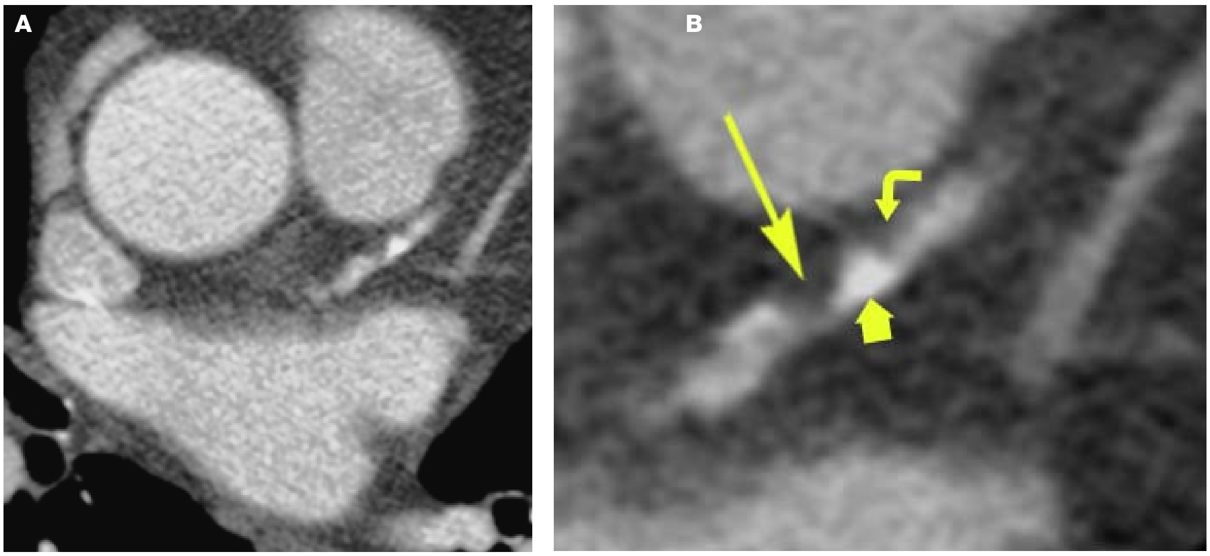

Figure 13. Severe CAD. [A] High-grade stenosis of LAD demonstrated by CCTA. [B] Close-up of axial CCTA verifies > 70% LAD stenosis. The obstructing mixed plaque consists of lipid (long arrow), fibrous tissue (curved arrow), and calcium (short arrow) by CT Hounsfield unit measurements.

REFERENCES

1. Boone JM. Multidetector CT: opportunities, challenges, and concerns associated with scanners with 64 or more detector rows. Radiology 2006;241:334-337.

2. Dowe DA. The case in favor of screening for coronary artery disease with coronary CT angiography. J Am Coll Radiol 2007;4:289-294.

3. Dowe DA. Personal Communication, 2006.

4. Einstein AJ, Henzlova MJ, Rajagopalan S. Estimating risk of cancer associated with radiation exposure from 64-slice computed tomography coronary angiography. JAMA 2007; 298:317-323.

5. Galis ZS. Vulnerable plaque: the devil is in the details. Circulation 2004; 24:2123-2129.

6. Hendel RC, Patel MR, Kramer CM, Poon M. 2006 appropriateness criteria for cardiac computed tomography and cardiac magnetic resonance imaging: a report of the ACCF/ACR/SCCT/SCMR/ASNC/NASCI/SCAI/SIR. J Am Coll Radiol 2006; 3:751-771.

7. Kalia NK, Miller LG, Nasir K, et al. Visualizing coronary calcium is associated with improvements in adherence to statin therapy. Atherosclerosis 2006; 39:394-399.

8. Leber AW, Knez A, White CW, et al. Composition of coronary atherosclerotic plaques in patients with acute myocardial infarction and stable angina pectoris determined by contrast-enhanced multislice computed tomography. Am J Cardiol 2003; 91:714-718.

9. Leschka S, Alkadhi H, Plass A, et al. Accuracy of MSCT coronary angiography with 64-slice technology: first experience. Eur Hear J. 2005; 26:1482-1487.

10. Perisinakis K, Theocharopoulos N, Karkavitsas N, Damilakis J. Patient effective radiation dose and associated risk from transmission scans using 153Gd line sources in cardiac SPECT studies. Health Phys 2002; 83:66-74.

11. Schoenhagen P, Halliburton SS, Stillman AE, et al. Noninvasive imaging of coronary arteries: current and future role of multi-detector row CT. Radiology 2004; 232:7-17.

12. Schoepf UJ, Zwerner PL, Savino G, et al. Coronary CT angiography. Radiology 2007; 244:48-63.

13. Schoepf UJ, Becker CR, Ohnesorge BM, Yucel EK. CT of coronary artery disease. Radiology 2004; 232:18-37.