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Cardiac Computed Tomography, Changing the Way We Look at the Heart

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ABSTRACT

Cardiac computed tomography angiography (CCTA) produces excellent anatomic information of the coronary arteries and other cardiac structures. A high negative predictive value (99%) for the exclusion of coronary lesions establishes CCTA as a highly effective noninvasive alternative to invasive coronary angiography. It is, however, less accurate for determining degrees of lesion severity, and intermediate grade lesions require either physiologic stress testing or invasive coronary angiography. CCTA allows visualization of the vessel wall so plaque can be classified as soft, calcified, or mixed on the basis of Hounsfield units. Precise quantification of the plaque burden is readily performed with coronary artery calcium scoring (CACS). This measurement of plaque burden is one of the most predictive of future cardiac events and mortality available. CCTA also serves as an excellent tool prior to surgical and percutaneous cardiac procedures. CT scanning continues to evolve as an imaging modality for all stages of the treatment of cardiac disease: CACS for risk assessment for asymptomatic patients, CCTA to evaluate patients with symptoms, and cardiac CT to plan cardiac procedures.

INTRODUCTION

Coronary artery disease (CAD) remains the leading cause of morbidity and mortality worldwide. Yet, as many as half of those who die had no prior diagnosis of heart disease, thus, the impetus to develop accurate tests for the diagnosis of CAD. The ability to diagnose CAD has improved vastly since the introduction of ECG-based exercise testing. Stress testing accompanied by either echocardiographic or nuclear imaging has evolved from a method of diagnosing obstructive CAD to a prognostic tool. An individual with a negative stress test has been shown to have a <1% chance of death or myocardial infarction (MI) in the subsequent year. As such, stress testing has established itself as the gatekeeper for invasive coronary angiography (ICA).

Computed tomography (CT) acquires images as the X-ray source, aimed at the detector on the opposite side of the gantry, rotates 360 degrees around the subject, then compiles those images to create an accurate representation of the subject. Non-moving subjects are relatively easy to display as static images with this technology, but the constant motion of the heart long remained a challenge for earlier CT technology. While the heart is beating, it changes its shape and physical relationship to its neighboring structures. The X-ray detectors in the CT gantry are rotating around the patient, changing the physical relationship between the heart and detector. The solution to this interrelationship of motion was to artificially stop the heart in order to image it. There are two phases in the cardiac cycle in which the heart is relatively still, at the end of systole and at the end of diastole, like the pendulum, which momentarily freezes at its zenith before swinging back down. If the CT scanner is fast enough, computer algorithms use the ECG to gate the rhythm of the heart to predict the heart's hesitation as it swings from diastole to systole, and the heart could be frozen in time to allow it to be imaged.

Cardiac computed tomography angiography (CCTA) initially started with electron beam computed tomography (EBCT), as this technology was fast enough to capture the heart in motion. Serial, overlapping cross-sectional images 1.5 mm or 3 mm thick are acquired during an inspiratory breath hold. Depending on the patient's heart rate, an EBCT took 30–40 seconds and was better suited for general cardiac imaging, function determination, and calcium scoring rather than coronary artery imaging. Multi-detector CT acquires a continuous spiral data set with overlapping images with submillimeter cuts and is better suited for imaging the coronary arteries. Speed of acquisition is essential to minimize the effect of

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Table 1. Cardiac computed tomography patient preparation

Heart Rate	Metoprolol tartarate	Dose
>60 bpm	50 mg orally	1 and 6 hrs prior to CCTA
>80 bpm	100 mg orally	1 and 6 hrs prior to CCTA
Patients on a beta blocker should take an extra 1/2 dose 1 hr prior to CCTA		

Heart Rate	Diltiazem	Dose
>60 bpm	30 mg orally	1 and 6 hrs prior to CCTA
>80 bpm	60 mg orally	1 and 6 hrs prior to CCTA
Patients on a Ca blocker should take an extra 1/2 dose 1 hr prior to CCTA		

bpm=beats per minute; CCTA=cardiac computed tomography angiography; Ca=calcium

cardiac motion on the image. Advances in detector technology have miniaturized the X-ray detector, which can now rest on a fingertip. The smaller detector arrays can be rotated around the patient more quickly, completing a rotation in a third of a second.

Initial systems had 4 detector rows, which have evolved to 16 and then 64 detector rows. A greater number of detectors covers a larger distance per rotation, shortening scan and breath hold time.[1] Acquisition of a cardiac data set typically required 20 seconds on the 16-slice systems, and that has decreased to 5 seconds on the 64-slice systems. Faster scanning minimizes the opportunity to induce motion artifacts from premature contractions or respiratory motion. Recently, one vendor has developed a scanner with two 64-detector arrays within the gantry positioned at 90 degrees relative to one another. With two arrays of detectors, the 360-degree arc around the patient is completed in half the time, a great improvement in spatial resolution.[2] Sixteen- and 64-detector scanners are only capable of imaging a portion of the heart each rotation; a series of five images must be registered, along with the ECG data to align the data in order to arrive at a clean image. If this alignment is not done perfectly, this misregistration artifact will make the image appear like a sloppy stack of poker chips as opposed to a tidy cylinder. Another vendor has released a CT scanner with 320 detector rows, which allows scanning of the entire heart in 1 cardiac cycle, minimizing motion artifact, eliminating misregistration artifact, and improving image quality.[3]

PATIENT PREPARATION

Radiographic contrast agents are intravenously injected during the CCTA, so the patient undergoing a CCTA should not have significant renal impairment. Approximately 70 mL to 90 mL of contrast are injected during a 64-detector CCTA. In cases of milder degrees of renal dysfunction, the risk of contrast-induced nephropathy should be weighed and alternate forms of testing should be considered. Consultation with a cardiologist to ascertain the pretest probability of obstructive CAD and/or a nephrologist to assess the risk of nephrotoxicity may be helpful. Patients should not eat prior to the test, as some patients become nauseated with contrast injection. As always, compounds containing metformin should be withheld for 48 hours when performing any procedure that involves the use of iodinated intravenous contrast.

A regular heart rate is necessary during the scan to avoid motion artifact as discussed above. Lying in the atrioventricular groove, the mid right coronary artery is most prone to this type of artifact. Pretreating with an oral beta blocker to achieve a regular heart rate of approximately 60 beats per minute is immensely helpful in obtaining diagnostic images (Table 1). Patients should refrain from consuming caffeine before the study. Patients with atrial fibrillation are not candidates for CCTA for the evaluation of obstructive CAD as the irregularly irregular rhythm of the heart thwarts the CCTA.

RADIATION

The high quality images obtained during much of the cardiac cycle allowed CCTA to develop toward a ''one-stop shop'' for cardiac imaging. The ability to acquire data providing left ventricular function and visualization of the pulmonary, coronary, and thoracic aorta arterial systems delivers considerably large doses of ionizing radiation to patients. Coronary artery calcium study (CACS), a simpler test requiring lower resolution, exposes an individual to a small dose of radiation, which at our institution averages 1 millisieverts (mSv). The mean dose in the observational PROTECTION I study involving 120 CCTA sites

worldwide was 12 mSv (equal to 600 chest X-rays or 1.2 × the dose of an abdominal CT).[4] However, higher doses are not uncommon. Much of this dose is directed to the lungs and breast with significant scatter to other adjacent organs. Stress myocardial perfusion imaging with single isotope agents such as technetium deliver similar doses, while dual isotope studies (thallium and technetium) reach considerably higher levels.[5] The fear of radiation-induced cancer accelerated the adoption of techniques that decrease radiation dose. ECG modulation and lowering tube voltage are readily available techniques and reduce radiation dose by 20% and up to 50%, respectively. CT radiation doses of <5 mSv can be achieved by turning on tube current only very briefly during mid diastole. This is known as prospective gating and has recently become a standard feature on all new CT scanners. One disadvantage of obtaining limited data through only a portion of the cardiac cycle is that ventricular function cannot be determined. In a small number of cases, a portion of one of the coronary arteries may not be clearly visible due to motion artifact (usually the mid right coronary artery) and images from other phases of the cardiac cycle have to be examined, which is not possible if prospective triggering is employed during acquisition. In a recent paper, the diagnostic evaluability on a per segment basis was only slightly lower (93% vs. 96%) in prospective vs. retrospective gating.[6]

CONTRAINDICATIONS

As discussed above, because CCTA depends upon a regular heart rhythm, patients with atrial fibrillation or other irregular rhythms should not undergo CCTA. Relatively immobile structures, such as the left atrium, however, can still be imaged. Iodinated contrast agents are injected for CCTA, so patients with renal impairment should not be routinely referred for CCTA. Patients are exposed to ionizing radiation that may increase the risk of cancer. Younger patients may be more sensitive to radiation and have a longer lead time to manifest the effects of radiation. Therefore, the age of the subject should be factored in when considering referral to CCTA.[7] Significantly obese patients will attenuate X-ray penetration and degrade images. Due to artifact from heavy calcium or metal of stent struts, CCTA, although not contraindicated, should be carefully considered in patients with stents or known heavy calcification.

PRESENT USES

Although it is invasive and has its own limitations, coronary angiography has remained the gold standard for the diagnosis of obstructive CAD. In recent years, however, clinical studies support the effectiveness of CCTA for exclusion of significant CAD. In more than 30 studies, CCTA has been compared to ICA in more than 2,000 patients.[8] Most single-center studies reported high sensitivities, specificities, and negative predictive values (NPVs) for obstructive CAD, defined as either ≥50% or ≥70%. A multicenter study using 16-slice CT revealed that the sensitivity, specificity, and positive predictive value (PPV), and NPV for detecting >50% luminal stenosis were 85%, 91%, 36%, and 99%, respectively.[9] One of the reasons for the lower PPV was a high number of unevaluable coronary segments, 29%. This study sought to evaluate all segments at least 2 mm in diameter, pushing the envelope of the technology of the time.

More recently, a prospective, blinded, multicenter study of 64-slice CT in patients with chest pain referred for ICA revealed a sensitivity of 95% and 94% for thresholds of ≥50% and ≥70%, respectively, specificity of 83%, and an NPV of 99%. The study was conducted in patients without previously diagnosed CAD.[10] Last year, another multicenter trial comparing CCTA to ICA revealed that CCTA accurately identified which patients had at least one vessel with >50% stenosis and which patients would subsequently undergo intervention.[11] CCTA was 85% sensitive, 90% specific, with a 91% PPV and 83% NPV for the detection of significant stenosis. More than half of the 291 patients in this trial had obstructive CAD (Figures 1 and 2).

Several clinical studies support the practicality and accuracy of CCTA for evaluation of patients with chest discomfort and inconclusive stress testing. If the results are normal, ICA can be safely avoided. Other appropriate indications for CCTA include exclusion of significant CAD in patients with new onset heart failure, suspected coronary anomalies (Figure 3), evaluation of pericardial conditions, and possibly tumors.[12] Advanced allograft vasculopathy can be detected in heart transplant patients with a higher sensitivity than dobutamine stress echocardiography. Additionally, early vasculopathy can also be seen by CCTA but not by dobutamine stress echo (Table 2).[13]

At least 6 studies have evaluated the safety and accuracy of CCTA in the triage of chest pain patients in the emergency department (ED). The high NPV of CCTA is the strength of this tool and makes it an excellent resource for the evaluation of chest pain. Raff, et al. performed the largest published randomized trial of CCTA for the evaluation of low-risk chest pain in the ED.[14] The investigators randomized 197 patients in the ED to CCTA or serial cardiac enzymes followed by nuclear stress testing. Patients with

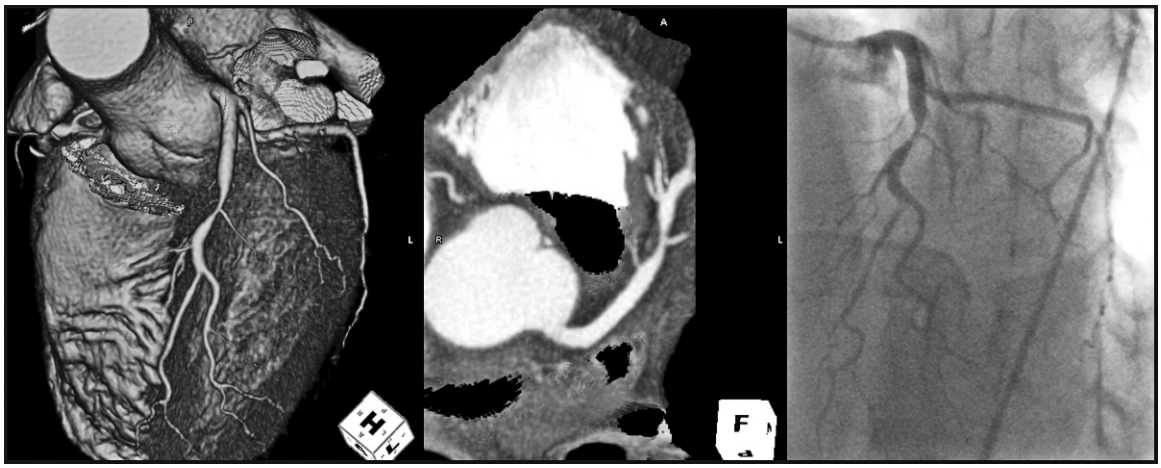

Figure 1. Left: A volume-rendered image of the heart demonstrates a severe stenosis of the proximal segment of the left anterior descending artery (LAD). Middle: A maximum-intensity projection demonstrates the severe stenosis of the proximal LAD; the plaque in the vessel wall is also visible. Right: The patient was referred for invasive angiography that confirmed the severe proximal stenosis, which was successfully stented.

abnormal test results underwent angiography; those with normal studies were discharged from the ED. CCTA successfully excluded coronary disease as the cause of chest pain or identified significantly obstructive CAD in 75% of the patients. The remaining 25% underwent nuclear stress testing for intermediate lesions by CCTA per protocol. Both strategies were 100% safe. CCTA resulted in quicker diagnosis compared to stress testing (3.4 hours vs. 15 hours, $p<0.001$) and did so more cheaply ($1,586 vs. $1,872, $p<0.001$). This study is being repeated as a multicenter trial and should be reported soon.

Unlike cardiac enzymes and ischemia evaluation with stress testing, CCTA provides anatomic information of non-cardiac structures, which is a further strength of CCTA when evaluating chest pain. The simultaneous exclusion of other life-threatening conditions, such as thoracic aortic dissection and pulmonary embolism, can be accomplished if the CT technician is advised prior to obtaining the scan to include the aortic arch and to time the injection appropriately. Currently it is advisable not to routinely include a pulmonary CTA at the same time as a cardiac and thoracic CTA. The additional coverage increases the radiation exposure, and the timing of contrast administration and image acquisition are different for the evaluation of the pulmonary and coronary circulations. Chest discomfort associated with cocaine use is often associated with minor troponin elevations in the ED. Hoffman and colleagues compared the findings of 44 patients with acute cocaine use who presented to the ED with chest discomfort with 132 matched controls. Those with cocaine use had a 6-fold increased likelihood of acute coronary syndrome, but this was not associated with a higher prevalence or extent of coronary atherosclerotic plaque.[15]

In a study of 1,653 patients who underwent CCTA for non-emergent conditions, 21% of patients deter-

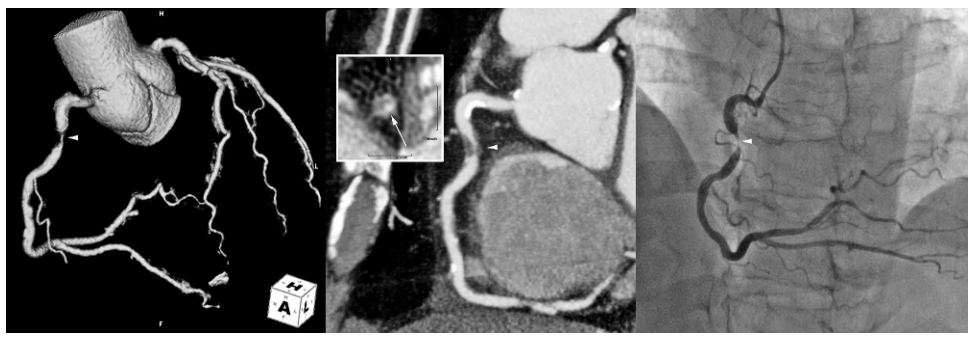

Figure 2. A 59-year-old man with hypertension and hyperlipidemia complained of chest pain. Stress echocardiogram did not reveal ischemia. Left: Cardiac computed tomography angiography reveals severe stenosis of the middle segment of the right coronary artery (RCA). Middle: A maximum-intensity projection demonstrates severe stenosis of this segment of the RCA. (Inset: Cross-sectional image of the stenosis demonstrates a tight stenosis and non-calcified plaque in the wall.) Right: Invasive angiogram confirms severe stenosis that was successfully stented.

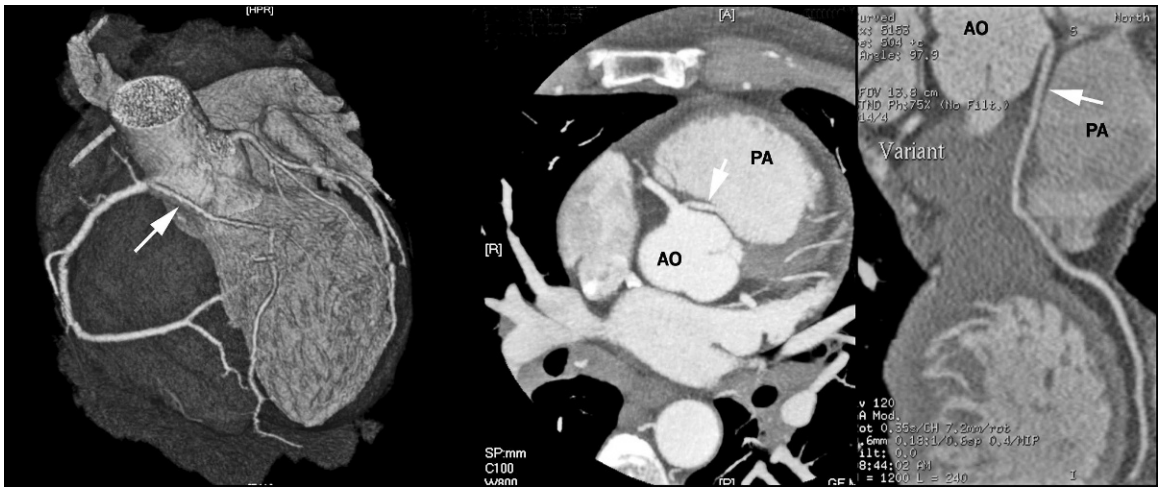

Figure 3. Center: Cardiac computed tomography reveals the anomalous origin of the left anterior descending artery (LAD) from the right coronary sinus (arrow). Left: A volume-rendered image depicts the anomalous LAD. The maximum-intensity projection demonstrates the LAD (arrow) coursing between the aorta and the pulmonary artery. Right: Confirmation of the anomalous coronary. AO=aorta; PA=pulmonary artery

mined to be low Framingham risk had significant plaque and were identified as targets for statin therapy. On the other hand, 26% of patients on statins had no detectable plaque.[16] Thus, patients with little or no plaque might be subjected to lifelong drug therapy, whereas many others with substantial plaque might be insufficiently treated, or not treated at all.

CACS

Clinical risk assessment tools such as the Framingham risk score are based on fairly robust data and have traditionally been used to identify the ''vulnerable patient'' and guide the intensity of medical therapy. Individuals who are estimated to have a <10% chance of sustaining a cardiovascular event in the next 10 years are classified as low risk.

Table 2. Appropriate indications for cardiac computed tomography[12]

Symptomatic Evaluation of Chest Pain
Intermediate pretest probability, ECG uninterpretable, unable to exercise
Symptomatic Evaluation of Cardiac Structures
Evaluation of anomalous coronary arteries
Symptomatic Acute Chest Pain
Intermediate pretest probability, no ECG changes, negative enzymes
Evaluation of Chest Pain Syndrome
Uninterpretable or equivocal stress test
Morphology
Assess coronary arteries in new heart failure patient for etiology
Assess complex congenital heart disease, including coronaries, chambers, and great vessels
Evaluation of Intra- and Extracardiac Structures
Evaluate cardiac mass
Technically limited echo, MRI, or TEE images
Evaluate pericardium or pulmonary veins
Coronary vein mapping prior to biventricular pacing
Evaluation of Aortic and Pulmonary Artery Pathology
Aortic dissection
Pulmonary embolus

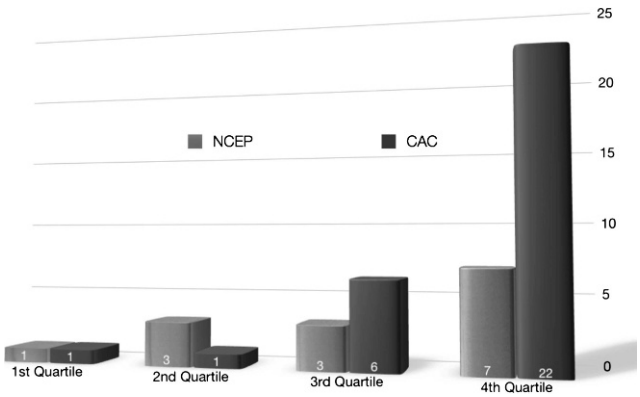

Figure 4. Odds Ratio of Cardiovascular Events. Subjects divided into quartiles based on CAC and by presence of traditional risk factors. CAC=coronary artery calcium; NCEP=National Cholesterol Education Program

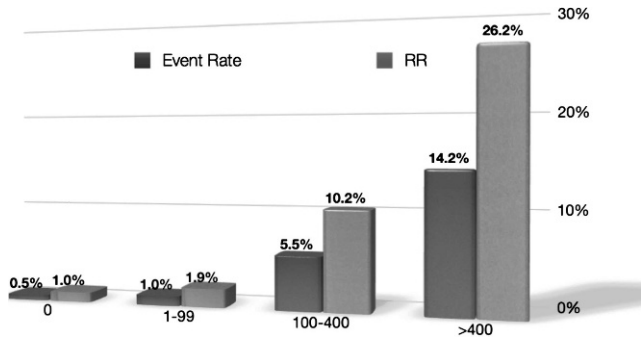

Figure 6. Coronary Calcium Score and All Coronary Disease Events. Coronary disease events include coronary death, nonfatal myocardial infarction, coronary bypass graft surgery, and coronary intervention. Relative risk is compared to the event rate of subjects with calcium score of 0 (n=4,613).[1]

Those with a ≥20% chance are high risk and those in between 10% and 20% are intermediate risk. CAC scoring has been proposed to further stratify the intermediate risk group (Figure 4). Calcium deposits form within coronary plaque during relatively early stages of atherosclerosis. Calcium can be easily detected by CT and a value ≥130 Hounsfield units for 2 adjacent pixels is used as the threshold (Figure 5). A CACS of 0 is generally associated with no atherosclerosis and can reclassify an individual's risk of MI as derived from traditional coronary risk factors. Scores of 1–100 generally denote minimal atherosclerosis and no obstructive disease, whereas scores >400 denote significant atherosclerosis and possible obstructive disease. The extent of calcification increases with age, but there are also gender and ethnic differences. Males have higher calcium scores than women, and Caucasians generally have higher scores than African Americans and Chinese.[17]

The prognostic significance of a CACS of 0 depends on the underlying population. In asymptomatic patients, the absence of coronary calcium carries a <1% chance of MI. In the St. Francis Heart Study, the event rate of MI for individuals with a CACS of 0 was 0.54% and for a CACS ≥400 was 14%. Although the event rate is low, the relative risk is 26.2[18] (Figure 6). As a risk factor, diabetes is a coronary disease equivalent in determining treatment. CACS remains an accurate predictor of cardiovascular events in the presence of diabetes (Figure 7). In an analysis of 13 studies comprising 71,595 asymptomatic patients (65% men) followed for 32 to 102 months (mean 50 months), 0.47% patients without CAC had a cardiovascular event compared with 4.14% patients with CAC. High sensitivity CRP (hsCRP) has been advocated as a marker of vascular inflammation and risk factor for MI. Park et al followed 1,461 patients without CAD or diabetes for 6 years and found increasing risk for MI, coronary death, and other cardiovascular events with increased CACS and levels of hsCRP. Participants were divided into low, medium, and high CACS and high and low hsCRP. Compared with the reference group (low hsCRP and low CACS), individuals with high CACS and low hsCRP had a relative risk of 4.4[19] (Figure 8).

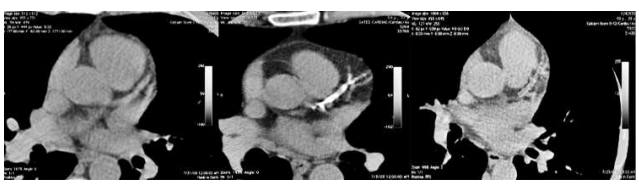

Figure 5. Coronary Artery Calcium Scoring. Left: Normal study. Center: A 37-year-old man with mixed dyslipidemia and family history of premature atherosclerosis, calcium depicted as bright white. FRS: 6%, CACS: 506. Right: A 57-year-old man with mild hyperlipidemia and a family history of premature CAD. Coronary calcium highlighted in pink. Calcium in bone of rib also noted. FRS: 9%, CACS: 595. FRS=Framingham Risk Score; CACS=coronary artery calcium score; CAD=coronary artery disease.

In 7 studies consisting of 3,924 symptomatic patients, 921 patients (23%) did not have any evidence of CAC. These patients were followed for a mean of 42 months. Of the 921 patients without CAC, only 17 patients (1.8%) had a cardiovascular event during follow-up, as opposed to 270 of the 3,003 patients (8.99%) with CAC, five times the event rate compared to those without CAC.[20]

Berman, et al. studied the relationship between myocardial perfusion imaging and CACS. As expected, the frequency of abnormal stress tests increased with higher calcium scores. Among patients with a calcium score <100, myocardial ischemia detected by

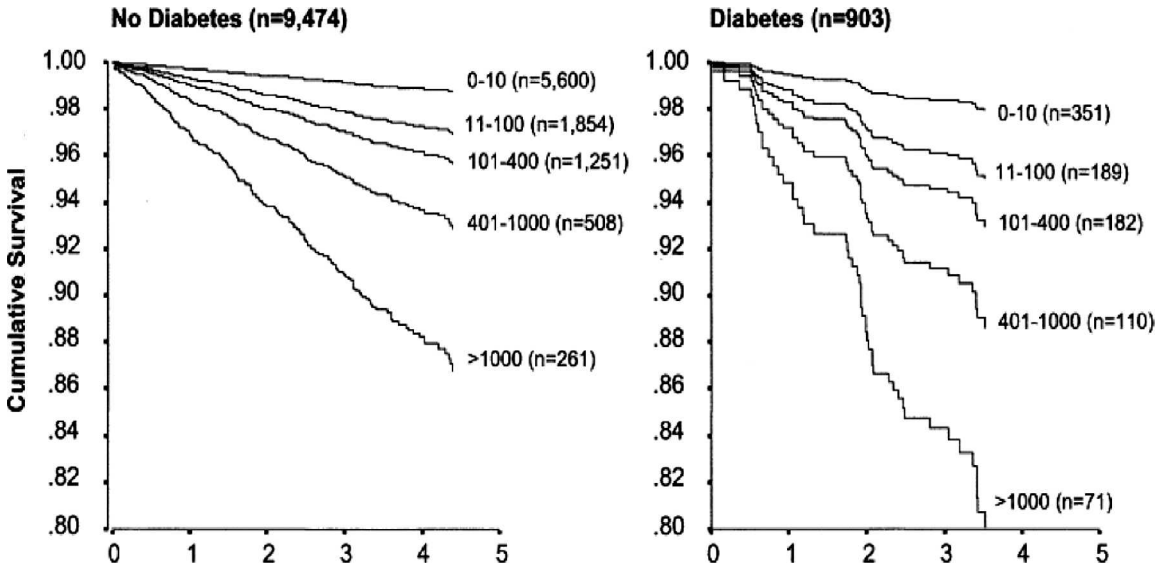

Figure 7. CACS Predicts Cumulative Survival in the Presence or Absence of Diabetes. Increasing CACS predicts lower survival rates. This relationship holds true regardless of diabetic status.[2] CACS=coronary artery calcium score

stress testing was rare, occurring in <2% of individuals. The presence of symptoms increased the likelihood of an abnormal stress test for calcium scores >1000. In individuals with CAC scores >400, and those with scores >1000, stress tests were abnormal in roughly 10% (7% and 12.2%) and 20% (15.3% and 32.5%), respectively (Figure 9).[21] The authors derive two conclusions. First, individuals' CAC scores <100 do not need further noninvasive testing as the likelihood of detecting ischemia is low. Annual stress tests in this group of individuals are unnecessary. Second, some patients with normal stress tests have extensive atherosclerosis by CAC criteria. A CACS may be an appropriate follow-up test in individuals despite a normal stress test.

EMERGING USES

Definition of the anatomy of the chambers of the heart is one of the emerging technologies of cardiac CT. Atrial fibrillation may be precipitated by foci located in the pulmonary veins; these foci may be ablated with percutaneous procedures. Cardiac CT is performed prior to the ablation procedure; the images are then imported into a navigation system in the electrophysiology laboratory. The incorporation of the cardiac CT data with the electrophysiology laboratory navigation system creates a three-dimensional model of the left atrium to assist the electrophysiologist in performing the ablation more efficiently and completely. Atrial fibrillation places the patient at risk of stroke due to the formation of thrombus within the left atrial appendage. A percutaneous procedure has been developed to percutaneously occlude the left atrial appendage to obliterate this source of throm-

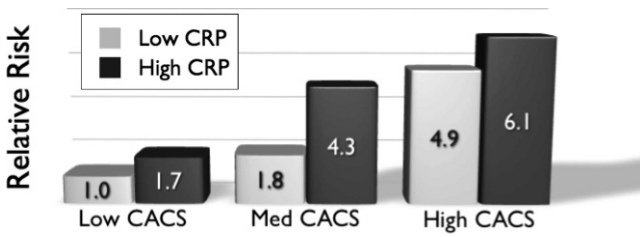

Figure 8. Relative Risk of Nonfatal MI and Coronary Death. Subjects with low CACS and low CRP serve as the reference group to determine relative risk compared to medium or high CACS or CRP. High CACS placed subjects at high relative risk whether they had low or high CRP.[3] MI=myocardial infarction; CACS=coronary artery calcium score; CRP=C-reactive protein

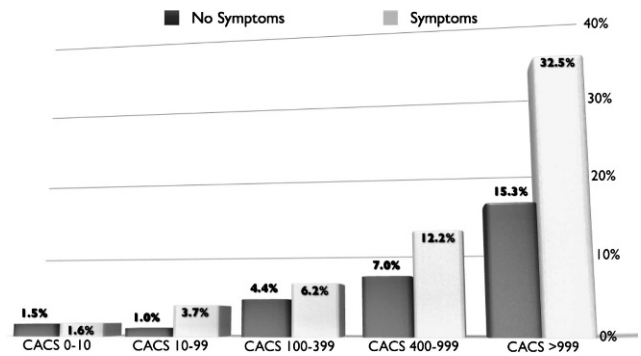

Figure 9. Coronary Artery Calcium Score as a Predictor for Ischemia on Stress Testing. The ordinate depicts the percentage of patients with ischemia on stress testing. Increasing CACS increases the likelihood of ischemia regardless of the presence of symptoms. Similarly, low calcium scoring predicts low likelihood of ischemia.[4] CACS=coronary artery calcium score

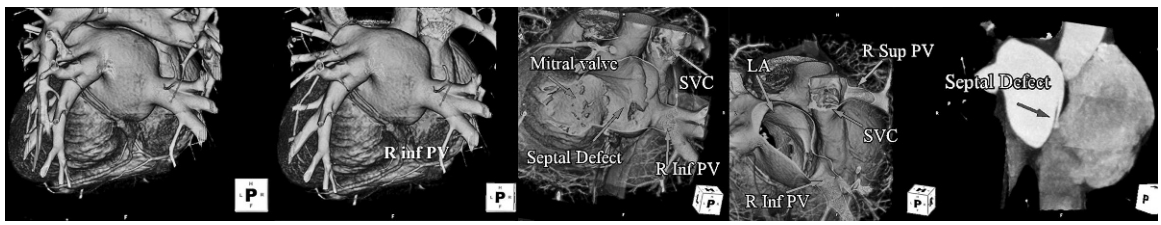

Figure 10. Anomalous Pulmonary Venous Return in a Patient with Atrial Septal Defect. Left: Posterior view of volume-rendered image of the heart as evaluation prior to percutaneous closure of ASD. Second panel: Pulmonary artery extracted from the volume-rendered image. Third panel: Volume-rendered image of a cutaway oblique lateral view of the heart. The septal defect is seen, as is its relationship to the mitral valve, SVC, and R inf PV. Fourth panel: Volume-rendered image of a cutaway oblique posterior view of the heart. The single right-sided pulmonary vein that returns to the LA is noted at the bottom of the figure. The anomalous pulmonary vein returns oxygenated blood to the SVC. Right: The septal defect is seen in cross-section on a maximum-intensity projection. ASD=atrial septal defect; R inf PV=right inferior pulmonary vein; SVC=superior vena cava, LA=left atrium; R sup PV=right superior pulmonary vein

bus. Cardiac CT provides the capability to evaluate the anatomy of the left atrial appendage for diameter of the orifice length and identification of the lobes of the appendage to allow proper planning and sizing for the procedure.

Atrial septal defects are now commonly closed by percutaneous procedures that deploy the appropriately sized device to prevent shunting between the left and right chambers of the heart. Transesophageal echocardiography has been the standard preprocedural imaging modality for the evaluation of the septal defect prior to closure. The size and location of the septal defect must be evaluated, but the pulmonary veins that empty into the left atrium must also be visualized. Some septal defects are associated with anomalous pulmonary venous return, that is, they do not return to the left atrium (Figure 10). Anomalous pulmonary venous return must be corrected surgically; identifying this anomaly precludes percutaneous closure of the atrial septal defect. Like fluoroscopy, transesophageal echo is limited as a two-dimensional imaging modality attempting to define three-dimensional objects. We have an ongoing trial evaluating the ability of cardiac CT to image the atrial septal defect prior to closure to predict the device need for closure.

Newer scanners, with 320 detectors covering a greater area, have a unique capacity to cover the entire heart without moving the patient. Whole organ scanning allows this new scanner to perform perfusion imaging. The scanner acquires the images over time. The scanner images the whole heart at time zero, then repeats imaging of the heart at one- or two-second intervals. By imaging over time and acquiring images of the entire organ, the scan demonstrates how the organ is perfused. Whole organ coverage allows the scanner to produce CT angiography that plays like a traditional angiogram that can be applied to acute stroke therapy. Using pharmacologic agents to simulate stress, this perfusion imaging will demonstrate areas of ischemia. This technology can also be applied to imaging of the brain, demonstrating perfusion defects of the brain. This perfusion imaging will stratify which stroke patients have brain infarcts and which have areas that are merely ischemic that may recover with reperfusion therapy.

CONCLUSION

For people without symptoms who are at intermediate risk for CAD, CACS will define their prognosis. An elevated coronary calcium score >400 puts the patient at high risk for cardiovascular events. CAC scoring may underestimate true atherosclerotic plaque burden by leaving out noncalcific plaque. Therefore, it should not be used as a stand alone test for symptomatic patients. Patients with symptoms who are unlikely to have ischemic chest pain should be considered for CCTA. The compelling NPV of CCTA makes this an excellent tool for the evaluation of chest pain, in the clinic or in the ED. Providing true three-dimensional imaging, CCTA will become the standard imaging modality before percutaneous cardiac procedures. CCTA is a relatively new technology. As such, the technologies and applications of those technologies are continuing to evolve. And as technologies in various specialties grow, the application of this three-dimensional imaging modality to those specialties will grow in parallel.

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