The What and Why of Cardiac CT Angiography: Data Interpretation and Clinical Practice Integration

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Noninvasive visualization of the coronary arteries is the holy grail of cardiac imaging. Cardiac catheterization, the historic gold standard for coronary imaging, is invasive, costly, and often performed unnecessarily. Cardiac computed tomographic angiography (CCTA) is a widely available, cost-effective imaging modality that effectively images the coronary arteries. The most appropriate patient for a CCTA-guided approach to the evaluation of chest pain is the symptomatic patient at low to intermediate risk. Data are rapidly evolving to further validate the accuracy, prognostic ability, and cost-effectiveness of this technique. The current landscape of the American medical system and the rising cost of United States health care have led to skepticism concerning CCTA and its potential misuse. Technological misunderstanding and concern about excessive radiation exposure also threaten its growth. When used properly by appropriately trained physicians, CCTA adds significant value to the evaluation of chest pain and to the diagnosis of coronary artery disease.
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Key words: Cardiac computed tomographic angiography • Coronary artery disease • Chest pain • Coronary arteries

Symptoms referable to the cardiovascular system represent only 0.2% of all outpatient clinic visits in the United States. This small subset of patients accounts for more than $2 billion of the $13 billion in total US health care yearly expenditures for outpatient clinic visits.[1-3] Many noninvasive diagnostic tests may be used for chest pain patients with low to intermediate likelihood of disease. These include stress electrocardiography, stress perfusion single-photon

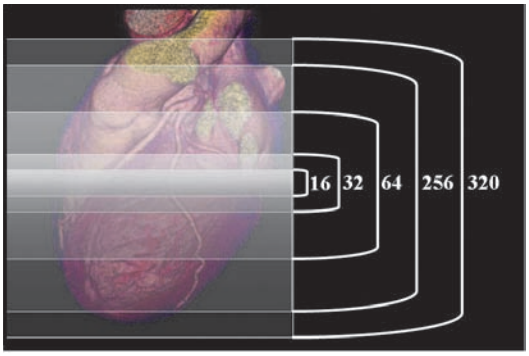


Figure 1. *An illustration of a volume-rendered (3-dimensional) reconstructed heart image and the coverage afforded by increasing the number of detector rows from 16 to 320. The 3-dimensional imaging is used for general anatomic survey and not to confirm coronary artery abnormalities. A 320-detector row computed tomography scanner allows complete coverage of the heart in 1 gantry rotation (1 heartbeat).*

emission computed tomography (SPECT) imaging, and stress echocardiography. Exercise testing with or without echocardiography or SPECT is indirect and of limited diagnostic accuracy.[4] Although these traditional, noninvasive tests may provide complementary prognostic, anatomic, and physiologic information, unnecessary repetitive diagnostic testing and the unnecessary cardiac catheterization (CC) that may result from indeterminate or borderline noninvasive test results are possible reasons for such a large expenditure in a small subset of patients.

The utility of a diagnostic testing strategy should account not only for the accuracy, prognostic ability, risk, and expense of the proposed test, but should also take into account the prevalence of disease in the tested population. It has been documented, for example, that noninvasive testing is more cost-effective in low-risk patient populations with chest pain, whereas CC is more cost-effective in high-risk patients.[5] Furthermore, logic dictates that diagnostic tests likely to rule out or rule in multiple possible diagnoses may be more valuable than those that exclude or include only 1 diagnosis.

Advances in cardiac computed tomographic angiography (CCTA) result in reproducible and accurate images of the coronary arteries.[6,7] Quick gantry rotation times of 360 ms or less and increasing numbers of detector rows of up to 320 have effectively frozen the heart in time, resulting in effective coronary artery imaging (Figure 1). A spatial resolution of near 0.4 mm permits visualization of arteries sized 1.5 mm or larger. Reduced detector size and collimation width result in nearly equal through-plane and in-plane spatial resolution, resulting in isotropic voxels that are necessary for distortion-free manipulation of 3-dimensional cardiac computed tomography (CT) data sets.

Advanced workstation capabilities allow the operator to manipulate these exquisite images in 3 dimensions. Thus, small structures such as coronary arteries may be precisely analyzed as they move through multiple imaging planes. Multiple reconstruction algorithms such as volume rendered 3-dimensional reconstructions, maximum intensity projections, and curved multiplanar reformatting add to the analytic accuracy of this technique (Figure 2).

Finally, improvements in imaging algorithms, such as prospective gating ("step and shoot" technique),[8] as well as more dose-saving, individualized CCTA protocols, result in significantly less radiation exposure. In addition, CCTA concomitantly images the myocardium, the great vessels, the pulmonary arteries, the pericardium, the cardiac valves, and other chest and upper abdominal structures, which may ultimately help explain the etiology of chest pain and exclude many diagnostic considerations.

Despite these favorable characteristics, CCTA is often criticized.[9] Possible reasons for this criticism include unfair interpretation and evaluation of modern data and poor understanding of the relative strengths and weaknesses of CCTA, as well as a misunderstanding of the most appropriate patient type for CCTA. Furthermore, there is a clear hesitance among public and private payers to add CCTA to their coverage plans. In addition, critics underestimate the caution and responsibility with which CCTA experts are advancing this field. This responsible approach includes a rapidly growing society dedicated to CCTA (the Society of Cardiovascular Computed Tomography [SCCT]),[10] self-imposed

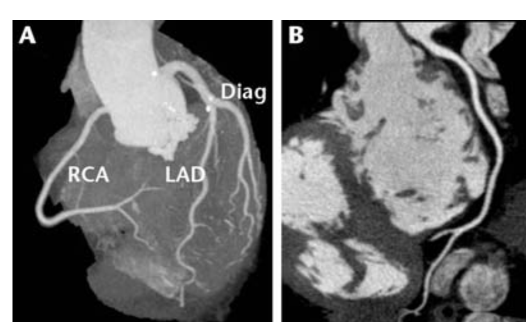


Figure 2. *Panel* **A** *depicts a thick maximum intensity projection. Here the image is multiple-slices thick (thickness is determined by the reader). The brightest pixel within the slice thickness is projected forward and visualized on the monitor. This technique results in longer visualized segments of the artery and makes more practical the virtual navigation through the coronary tree. Panel* **B** *illustrates a curved multiplanar reformatting, a format that reproduces a single, user-defined line in multiple planes and depicts this line in a single plane onto the screen. This technique allows an entire artery to be seen on the computer screen at once. RCA, right coronary artery; LAD, left anterior descending artery; Diag, diagonal.*

and rigid clinical practice training guidelines for those already in clinical practice, and, for fellows in training,[11,12] the establishment of a program to endorse private CCTA training courses,[13] the establishment of a CCTA certification board,[14] the pre-emptive development of CCTA appropriateness criteria,[15] and the creation of the *Journal of Cardiovascular Computed Tomography* to promote CCTA research and education.

Akin to all important technological innovations, future studies are necessary to further define and refine the role of CCTA. However, its place as a currently valuable diagnostic and prognostic cardiovascular imaging tool is sound. Yet critics attempt to hold CCTA to a much higher standard than any other imaging test in the history of medicine by demanding clinical outcomes data for a diagnostic test meant to identify and not to treat disease.[9]

Demand for proof that CCTA, on its own, can reduce the morbidity and mortality associated with coronary artery disease (CAD) is not reasonable because it is the treatments such as lipid modification, antiplatelet therapies, β-blockers, and angiotensin-converting enzyme inhibitors, along with lifestyle modifications such as exercise, weight reduction, and smoking cessation, that reduce cardiac event rates. The diagnostic examination itself does not reduce possible negative outcomes. An analogy would be mammography. It is not the mammogram that improves outcomes. On the contrary, the early treatment of the identified breast malignancy is what saves lives. Therefore, this is clearly an unreasonable expectation for a diagnostic imaging modality.

This article will review current data, rebut criticisms regarding CCTA, and propose a practical CCTA clinical integration model.

Validation Data

Native Coronary Arteries

To become clinically trusted and well accepted in the medical community, new diagnostic testing modalities must be subjected to and must withstand strict scientific rigor to determine accuracy, prognostic ability, safety, and cost-effectiveness. Validation studies are the first piece to a complicated puzzle of clinical evaluation. Although these proof-of-concept studies are necessary and important, they are only the first step toward the clinical relevance and acceptance of any new diagnostic test. The interpretation and judgment of these initial scientific studies must account for this important concept.

Two important meta-analyses by Hamon and colleagues[6,7] have been published to assess the accuracy of CCTA. These analyses have pooled the early single-center studies comparing 16-slice or greater CCTA to the gold standard of CC where coronary stenoses of 50% or greater were considered significant. In the first of these studies using scanners of 16 slices or greater,[6] only 4.2% of segments and 0.017% of patients were excluded for unsuccessful imaging. The pooled accuracy data from this study are summarized in Table 1. The subsequent analysis by this same group[7] compared 16-slice with 64-slice CCTA data. The mean rates of unevaluable scans for 16- and 64-slice scanners were 4.4% and 1.9%, respectively. The rate of unassessable segments ranged from 1% to 29% in 16-slice scanners versus 0% to 12% in 64-slice scanners. Table 2 depicts the pooled accuracy data from this second meta-analysis.

Take-home points from these 2 meta-analyses are that the power of CCTA lies in its negative predictive value (NPV), or its ability to rule out disease, and that the performance of CCTA improves with 64-slice CCTA when compared with 16-slice CCTA, especially with regard to sensitivity. The number of evaluable segments also improves dramatically with 64-slice versus 16-slice CCTA. Most likely, this finding results from improved coverage of the 64-slice scanners, resulting in a reduced scan time (fewer heart beats needed to complete the scan). Thus, arrhythmia and breathing artifacts are less problematic. Finally, the per-vessel and, more importantly, per-patient analyses fair better than per-segment

Table 1
Pooled Accuracy Data From a Meta-Analysis of CCTA Examinations*

	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Per Segment (n = 22,798)	81% (72%-89%)	93% (90%-97%)	67.8% (57.6%-78%)	96.5% (94.7%-98.3%)
Per Vessel (n = 2726)	82% (80%-85%)	91% (90%-92%)	81% (78%-83%)	92% (91%-93%)
Per Patient (n = 1570)	96% (94%-98%)	74% (65%-84%)	83% (76%-90%)	94% (89%-99%)

*The scanners were 16 slices or greater.
CCTA, cardiac computed tomographic angiography; CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value.
Data from Hamon M et al.[6]

Table 2
Pooled Accuracy Data From a Meta-Analysis Comparing 16-Slice CCTA Scanners and 64-Slice CCTA Scanners

	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
16-Slice				
Per Segment (n = 16,510)	77% (75%-79%)	91% (91%-92%)	60% (59%-62%)	96% (96%-96%)
Per Patient (n = 1292)	95% (93%-96%)	69% (66%-73%)	79% (76%-82%)	92% (88%-94%)
64-Slice				
Per Segment (n = 10,388)	88% (86%-89%)	96% (94%-97%)	79% (77%-81%)	98% (98%-98%)
Per Patient (n = 695)	97% (95%-98%)	90% (86%-93%)	93% (91%-96%)	96% (92%-98%)

CCTA, cardiac computed tomographic angiography; CI, confidence interval; PPV, positive predictive value; NPV, negative predictive value.
Data from Hamon M et al.[7]

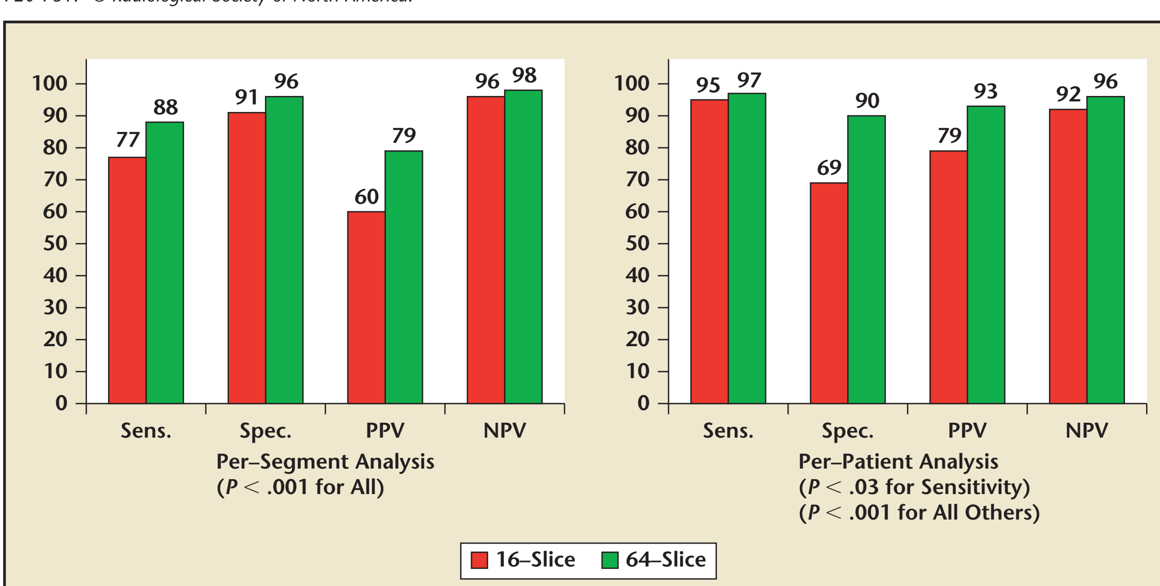
evaluations (Figure 3). For purposes of clinical decision making, the per-patient data are of most interest because these data drive the patient management decisions.

Three important multicenter prospective studies have also been performed to evaluate the accuracy of CCTA. The Assessment by Coronary Computed Tomographic Angiography of Individuals Undergoing Invasive Coronary Angiography (ACCURACY) study[16] was a prospective, multicenter study evaluating the use of 64-slice CCTA in adults presenting with chest pain who were referred for CC. A total of 16 sites and 232 patients participated. All scans were evaluated on a per-patient and per-segment basis. No vessel segments were deemed unevaluable. All segments were included regardless of patient or vessel calcium score, and patients were not excluded on the basis of body mass index.

The prevalence of obstructive CAD in this population was low, at 20%. For stenoses greater than 50%, the per-patient and per-vessel analyses were as follows: 93% versus 84% for sensitivity, 82% versus 91% for specificity, 62% versus 51% for positive predictive value (PPV), and 97% versus 98% for NPV. For stenoses greater than 70%, the per-patient and per-vessel data were 91% versus 85% for sensitivity, 84% versus 92% for specificity, 49% versus 33% for PPV, and 98% versus 99% for NPV. The reduced PPV may reflect the low prevalence of disease.

The Coronary Evaluation on 64 (CORE 64) study,[17] a prospective,

Figure 3. *Per-segment and per-patient accuracy data for 16-slice versus 64-slice cardiac computed tomographic angiography. Sens, sensitivity; Spec, specificity; PPV, positive predictive value; NPV, negative predictive value. Reprinted with permission from Hamon M et al.* Radiology. *2007;245:720-731.[7] © Radiological Society of North America.*



multicenter study performed at 9 hospitals in 7 countries and in 291 patients, assessed the accuracy of 64-slice CCTA in symptomatic patients age 40 years or older who were referred for diagnostic CC. Patients with a body mass index greater than 40 or a calcium score at or exceeding 600 were excluded. The prevalence of at least 1 obstructive lesion was high, at 56%. The visual, per-patient sensitivity, specificity, PPV, and NPV were 83%, 91%, 92%, and 81%, respectively. The visual, per-vessel accuracy data were as follows: For 3-vessel disease, the sensitivity was 75%, the specificity was 93%, the PPV was 83%, and the NPV was 89%. The left main (LM), left circumflex (LCX), and right coronary artery (RCA) disease accuracy data were as follows: For LM, 80% sensitivity, 88% specificity, 81% PPV, and 88% NPV; for LCX, 73% sensitivity, 94% specificity, 82% PPV, and 90% NPV; and for RCA, 71% sensitivity, 95% specificity, 84% PPV, and 90% NPV. The higher prevalence of disease in this study may explain the lower NPV.

Most recently, Meijboom and colleagues[18] published a multicenter, prospective study also using 64-slice CCTA in 433 symptomatic patients. The prevalence of at least 1 significant stenosis (≥ 50%) in this population was also high, at 68%. Nearly all (99%) patients who had significant CAD by CC were identified. In all patients with LM or 3-vessel disease, CCTA detected at least 1 significant stenosis, resulting in the correct clinical decision. However, 41 of 433 patients (9.4%) were incorrectly identified as having significant CAD.

On a per-patient basis, the sensitivity, specificity, PPV, and NPV in the study by Meijboom and colleagues[18] were 99%, 64%, 86%, and 97%, respectively. The per-vessel and per-segment accuracy data were 95% and 88% for sensitivity, 77% and 90% for specificity, 59% and 47% for PPV, and 98% and 99% for NPV. Stenosis severity was often overestimated in this study compared with conventional angiography. This can be explained by the inability of conventional coronary angiography (as just a "luminogram") to take into account the positive vascular remodeling that occurs in atherosclerosis. The per-patient evaluations were accurate and robust when compared with coronary angiography.

Large studies evaluating the accuracy of 256-slice and 320-slice scanners have not been published because these newer scanners have not yet been put into broad commercial use.

The preponderance of evidence to date concerning the accuracy of CCTA in evaluating native coronary arteries in symptomatic patients supports the power of CCTA in ruling out disease. The NPV is generally 95% or greater in low- to intermediate-risk chest pain populations and, thus, CCTA is most appropriate in this patient subset. Although the accuracy of CCTA in identifying 3-vessel disease and all significant lesions is modest, the accurate identification of any significant disease on a per-patient basis is powerful. It may be argued that the per-patient evaluation is the most clinically important because it will result in necessary CC (and avoidance of unnecessary CC).

Furthermore, the accuracy of CCTA must be interpreted in the context of the prevalence of disease. NPV will be much lower and PPV much higher in patients with high prevalence of disease, whereas NPV is higher and PPV is lower in patient populations with low prevalence of disease. This concept may explain the varying NPV among these 3 prospective CCTA trials (Figure 4).

The most appropriate patient for a CCTA-guided approach to the evaluation of chest pain is the symptomatic patient at low to intermediate risk. At this time, existing data and the published appropriateness criteria[16] do not support the use of CCTA in high-risk, symptomatic patients who may be best suited for CC, nor do they support CCTA as a screening test for patients in whom the benefits

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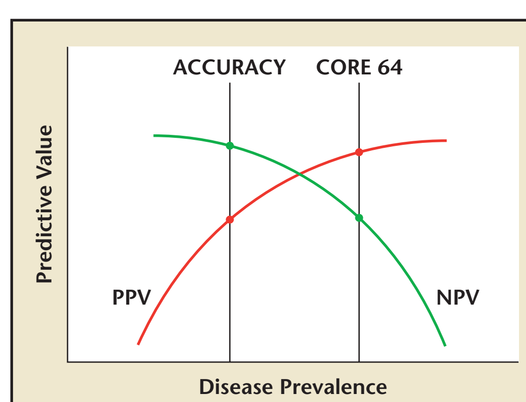


Figure 4. *The relationship between disease prevalence and predictive value. ACCURACY, Assessment by Coronary Computed Tomographic Angiography of Individuals Undergoing Invasive Coronary Angiography; CORE 64, Coronary Evaluation on 64; PPV, positive predictive value; NPV, negative predictive value. Courtesy of Michael Poon, MD.*

of CCTA may not justify the risks of radiation exposure and iodinated contrast administration. Future investigation is required before CCTA can be routinely recommended in these patient types.

Coronary Bypass Grafts

A meta-analysis of 16-slice CCTA versus 64-slice CCTA for coronary artery bypass patients has also been performed, which involved 15 studies and 723 patients.[19] Graft assessability (including the distal anastomoses) varied between 78% and 100%. The pooled sensitivity, specificity, PPV, and NPV in 2023 grafts for significant stenoses and for occlusion were as follows: a sensitivity of 97.6% (95% confidence interval [CI], 96%-98.6%), a specificity of 96.7% (95% CI, 95.6%-97.5%), a PPV of 92.7% (95% CI, 90.5%-94.6%), and an NPV of 98.9% (95% CI, 98.2%-99.4%).

CCTA in bypass patients performs very well when it is used to analyze the body of a bypass graft. Bypass grafts are generally larger caliber vessels (not subject to the limits of spatial resolution), and the bodies of bypass grafts do not demonstrate significant motion artifact. However, a word of caution is appropriate. Although it is important to accurately visualize the body of bypass grafts, it is equally important to clearly evaluate the anastomotic sites and the native, unprotected coronary arteries because clinically significant stenoses may reside in these locations as well. Yet, bypass anastomoses and native unbypassed coronary arteries are often more difficult to assess due to clips that may surround the anastomotic site and due to the more advanced, calcified atherosclerotic disease often present in the native vessels of bypassed patients. Thus, it is wise to use caution and clinical selectivity when choosing CCTA to evaluate coronary artery bypass graft patients.

Intracoronary Stents

Reports on coronary stent analysis with CCTA have been published as well. A meta-analysis by Hamon and colleagues,[20] which included 15 studies and 1175 stents using 16-slice CCTA or higher, reports that 13% of all stents were unassessable. The sensitivity for the stent analysis was 84% (95% CI, 77%-89%), the specificity was 91% (95% CI, 89%-93%), the positive likelihood ratio (PLR) was 12.22 (95% CI, 6.6-22.6), and the negative likelihood ratio (NLR) was 0.23 (95% CI, 0.17-0.31). For a test to be useful, generally accepted values for PLR and NLR are greater than 10 and less than 0.1, respectively.[21]

Abdulla and colleagues[22] published a meta-analysis on stent evaluation (270 intracoronary stents) in studies using only 64-detector CCTA. The accuracy of CCTA was as follows: a sensitivity of 80% (95% CI, 70%-88.5%), a specificity of 95% (95% CI, 92%-97%), a PPV of 80%, and an NPV of 95%. A more recent meta-analysis by Vanhoenacker and colleagues[23] reviewed 14 studies that used 16-slice or higher scanners in 400 patients and 1039 stents. The pooled sensitivity and specificity were 82% (95% CI, 72%-89%) and 91% (95% CI, 83%-96%), respectively. The PLR was 9.34 (95% CI, 4.68-18.62), and the NLR was 0.2 (95% CI, 0.13-0.32). The most important factor in determining the likelihood of diagnostic stent imaging was a stent diameter of 3 mm or greater.[21,24]

At this time, it is not advisable to routinely use CCTA for the sole purpose of intracoronary stent evaluation. The blooming artifact resulting from the stent struts will often preclude accurate in-stent luminal imaging. Presently, CCTA cannot reliably be counted on to determine patency and restenosis in stents smaller than 3.0 mm. Even in stents larger than 3.0 mm, visualization of the stent lumen is not guaranteed. Furthermore, it takes significantly more time and effort to reconstruct and analyze CCTA data for stents than for nonstented coronary segments. Thus, CCTA for stent imaging may be more appropriately performed in centers committed to cardiovascular imaging rather than in general CT imaging practices. Presently, CC remains the test of choice to evaluate in-stent restenosis. Reliable intracoronary stent imaging will depend on changes in stent design, improvements in CCTA spatial resolution, and, possibly, on the further development of dual-energy CCTA.

The Future

In the last few years, rapid advances in CCTA technology have been observed that may ultimately prove to increase the diagnostic accuracy of CCTA. The Aquilion One 320-slice scanner (Toshiba America Medical Systems, Inc., Tustin, CA) provides an unprecedented 160 mm coverage with 1 single 350 ms gantry rotation, virtually eliminating misregistration artifacts. The Brilliance iCT 256-slice scanner (Philips Healthcare, Andover, MA) provides 80 mm of coverage with a gantry rotation of 270 ms. Air-bearing technology was used to allow this improved temporal resolution (potentially allowing diagnostic imaging at higher heart rates).

The Discovery™ CT750 HD (GE Healthcare, Piscataway, NJ) uses a new Gemstone detector that is claimed to be 100 times more sensitive than the standard detector technology, resulting in improvements in spatial resolution, decreased calcium blooming artifact, and, perhaps, the ability to

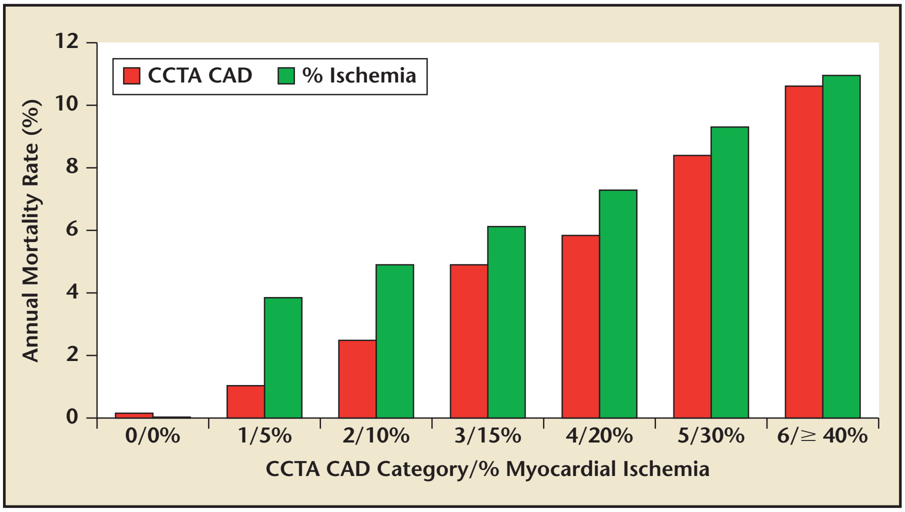


Figure 5. *A depiction of the annual mortality rate determined by CCTA category in red and by percent of myocardial ischemia in green. CCTA categories are as follows: 0, < 50% stenosis in 1 artery; 1, 30% to 49% stenosis with proximal disease in 1 artery or 1 stenosis of 50% to 69%; 2, 2 stenoses of 50% to 69% or 1 vessel of ≥ 70%; 3, 3 stenoses of 50% to 69% or 2 vessels of ≥ 70% or ≥ 70% in the proximal left anterior descending artery stenosis; 4, 3 vessels of ≥ 70% stenosis or 2 vessels of ≥ 70% stenosis with 1 stenosis in the proximal left anterior descending artery; 5, 50% to 69% left main stenosis; 6, ≥ 70% left main stenosis. Comparison of risk categories by CCTA versus percent of myocardial ischemia demonstrated a* P *value of .53, indicating no significant difference. CCTA, cardiac computed tomographic angiography; CAD, coronary artery disease. This figure is an adaption of two figures that were published in* Journal of Cardiovascular Computed Tomography, *Volume 2, Shaw LJ et al. Prognosis by coronary computed tomographic angiography: matched comparison with myocardial perfusion single-photon emission computed tomography. Pages 93-101.[29] Copyright © Society of Cardiovascular Computed Tomography 2008.*

successfully image smaller stents. Most recently, the SOMATOM Definition Flash (Siemens, New York, NY) uses dual-source 128 detector technology with a vendor-reported high-temporal resolution and coronary imaging at less than 1 mSV. Vendors have also reported radiation doses of below 10 mSv for combined perfusion and coronary imaging. Large, prospective studies are needed to confirm the potential benefits of these new technologies.

Prognostic Data

Although CCTA has not been shown to reliably predict ischemia,[25-27] its role as a prognosticator is emerging. The power of SPECT to predict cardiac events is well documented.[28] By comparing CCTA to SPECT, Shaw and colleagues[29] first identified the prognostic power of CCTA. They noted similar annual, risk-adjusted mortality rates in patients with varying degrees of CAD identified by CCTA as in those patients with varying degrees of ischemia detected by SPECT (Figure 5).

To date, 2 other important CCTA prognostic studies have also been published. Pundziute and colleagues[30] prospectively followed 104 consecutive patients presenting to the outpatient clinic with suspected CAD. CCTA was performed in all patients. In a multivariate analysis, coronary plaques, obstructive CAD, LM, and left anterior descending disease, number of coronary segments with obstructive plaques, and number of coronary segments with mixed plaques were independent predictors of cardiac events, driven mainly by revascularization. No events occurred in patients with no CAD versus 30% in patients with any CAD as detected by CCTA (P = .005).

In a larger study, Min and colleagues[31] prospectively evaluated 1127 consecutive patients ages 45 years or older who presented with atypical chest pain. CCTA was the primary diagnostic imaging modality. CCTA scans were assessed for the number of vessels involved, for the Duke prognostic CAD index for CC[32,33] as applied to CCTA, and for a novel coronary artery plaque score developed by the study authors to represent worsening extent of overall coronary artery plaque. In a multivariate analysis, the presence of plaque in increasing numbers of coronary arteries, moderate and severe plaque, and plaque in the LM were independent predictors of all-cause mortality. In addition, the Duke prognostic CAD index was a significant predictor of all-cause mortality (Figure 6).

These prognostic studies begin the next step toward clinical acceptance for CCTA by demonstrating the ability of CCTA to predict hard adverse cardiovascular outcomes. Certainly, more studies of this type are needed. Furthermore, additional studies are necessary to examine the role of CCTA in the context of other proven cardiovascular imaging modalities. In addition, it will be essential to validate the role of CCTA in clinical decision-making and in guiding cardiovascular disease management decisions.

A Rebuttal of the Criticism of CCTA

Much skepticism and criticism has surrounded the emergence of CCTA. Common criticisms include that CCTA is misused, overutilized, costly, and dangerous. Some editorials[9] and lay press publications[34] ignore and oversimplify the data and thus create an incomplete or misleading picture. There may be concerns that CCTA will escalate health care costs and decrease private insurance payer profits.

The CCTA evaluation process and its progression to a mainstream cardiac imaging modality must be

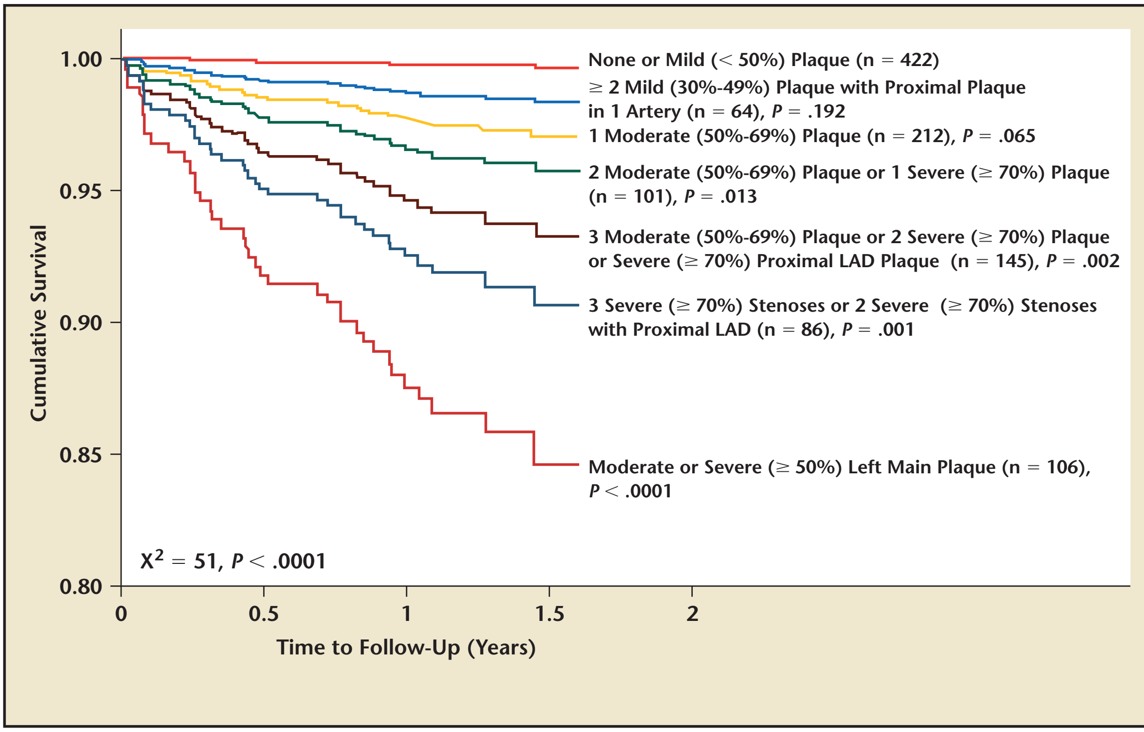


Figure 6. *Cumulative survival data for the Duke Prognostic Coronary Artery Disease Index as applied to cardiac computed tomographic angiography. LAD, left anterior descending artery. Reprinted from* Journal of the American College of Cardiology. *Volume 50, Min JK et al. Prognostic value of multidetector coronary computed tomographic angiography for prediction of all-cause mortality. Pages 1161-1170.*[31] *Copyright © 2007, with permission from the American College of Cardiology.*

handled with unbiased hands. CCTA experts and clinicians should be commended for their responsibility and expertise in introducing and developing CCTA. Nearly 5000 physicians and ancillary medical professionals have joined the Society for Cardiovascular Computed Tomography, a society dedicated to CCTA education, research, and responsible utilization. Clinical training guidelines,[11] a training course certification process,[13] verification of physician training,[12] a cardiovascular certification board,[14] and appropriateness criteria for the use of CCTA[15] were proactively created to ensure proper training, study, and application of this modality.

CCTA is frequently criticized for its significant radiation exposure, with claims that the radiation exposure with CCTA is severalfold higher than alternative coronary artery evaluation methods.[35] To the contrary, CCTA has raised awareness of the need for responsible diagnostic radiation use in all areas of patient care.

Findings of the Prospective Multicenter Study on Radiation Dose Estimates of Cardiac CT Angiography in Daily Practice I (PROTECTION 1) study[36] (no industry sponsorship) demonstrated wide variations in radiation dose (5.7 mSv to 36.5 mSV) among participating sites. This observational study included 50 sites worldwide and 1965 CCTA examinations performed during 1 month. Higher radiation doses were often found to result from a failure to use available dose-saving techniques that are often simple to add to institutional imaging protocols.

Technological advances and patient-specific CCTA protocols have led to marked reductions in CCTA radiation exposure. Dose modulation techniques available on all scanners have been shown to reduce effective doses by nearly 50%.[37] Reductions in radiation energy in thinner patients have also been shown to substantially reduce the radiation dose.[38] X-ray energy settings may be modified on all scanners. In addition, prospective imaging has reduced the CCTA radiation dose from 17.2 ± 2 mSv to 3.1 ± 1.5 mSv without compromising image quality.[39] These newer CCTA protocols result in effective doses of radiation that approach those of CC (4-10 mSv).[40] As a comparison, the effective doses for standard chest CT, high-resolution chest CT, abdominal CT, and pelvic CT are 6 to 7 mSv,[41] 1 mSv,[41] 13 mSv,[42] and 12 mSv,[42] respectively.

It is surprising that radiation exposure from CCTA has attracted so much attention because nuclear stress testing is ordered much more frequently and is associated with much higher average effective doses (14 mSv to 24 mSv).[40] Furthermore, frequently used dual-isotope protocols expose patients to average doses near 27 mSv. CCTA critics have not properly noted these data.

In addition, the claim of an estimated 2% excess risk of cancer from a single CCTA[42] scan is clearly an overestimate because CCTA administers radiation in a controlled setting to the chest with a focus on the heart. This excess risk assumption for CCTA is based on the cancer rates of atomic bomb survivors who received effective doses of 5 to 20 mSv.[42] It is biologically incorrect to compare the radiation exposure from 1 single CCTA to that experienced by an atomic bomb survivor.

It must also be noted that the risk of radiation-induced malignancy depends strongly on the patient's age at the time of exposure. Exposure at earlier ages increases future cancer risk. Most patients undergoing CCTA are in their fifth and sixth decades, and thus their excess risk is comparatively low. In fact, the estimated risk of future neoplasm (using older CCTA protocols) for a 60-year-old woman and a 60-year-old man are approximately 0.14% and 0.05%, respectively.[42] In addition, it may be argued that the risk of the morbidity and mortality that results from a failure to diagnose CAD at an early stage may be much higher than that of the radiation dose used to make this diagnosis.

Unnecessary radiation exposure from CCTA may be avoided by appropriate patient selection. At this time, CCTA is not appropriate as a screening test for asymptomatic individuals. Choi and colleagues[43] studied 1000 asymptomatic, middle-aged (≤ 50 years) patients who were self-referred for CCTA. They demonstrated that very few had any plaque (22%). Only 5% had a 50% or greater stenosis, and remarkably few (2%) had a 75% or greater stenosis. Only 15 cardiac events occurred in this study (1 unstable angina event and 14 coronary revascularizations). There were no observed myocardial infarctions or deaths, and no events were documented in patients shown to have no plaque. Thus, the risk-benefit ratio of CCTA in the asymptomatic patient does not justify its utilization in this population. Calcium scoring alone (1-2 mSV) may be a more appropriate screening test.

Claims of CCTA misuse, overutilization, and increased expense are not supported by a comparison of the 2007 Medicare carrier claims summary file to that of the 2006 claims summary obtained from the Center for Medicare and Medicaid Services.[3] Remarkably, in 2006 or 2007, CCTA did not make the list, which indicates that less than $50 million was spent on this modality. CCTA is included in the "heart image (3d), multiple" category. In 2007, $1.07 billion was spent on this broad category of advanced heart imaging versus $1.16 billion in 2006, a decline of $90 million.

In addition, Medicare spending for advanced heart imaging, echocardiography, and stress testing declined by at least $1.2 billion in 2007, whereas spending on CC was nearly $3.3 million less than in 2006. These data do not support overuse or misuse of CCTA and do not suggest excessive layering of diagnostic imaging tests when a CCTA-guided approach is used. Nor do these data confirm an increase in spending on cardiovascular imaging since the introduction of CCTA.

A report from the Cardiovascular Innovations (CVI) registry is consistent with these Medicare data. Fine and colleagues[44] demonstrated that among 20,000 cases in this "real-world" registry, in the 12 months following implementation of CCTA, there was a 5% and 8% drop in CC and stress nuclear scans, respectively, despite a concomitant 10% increase in patient volumes. A 5% drop in normal CC studies was also noted. These findings suggest appropriate utilization and an added value of CCTA. Furthermore, the CVI registry demonstrated an annual savings to the health care system for the 26 participating practices of nearly $7.5 million despite the aforementioned 10% rise in patient volumes, indicating that a CCTA-guided approach is cost-effective.

Finally, in 2 separate analyses, Min and colleagues have demonstrated cost savings of nearly $500[45] and more than $1000[46] in a CCTA-guided approach for chest pain patients when compared with a stress nuclear perfusion–guided approach. Clinical outcomes were similar in both groups. Furthermore, only 7.5% of patients who initially underwent CCTA were later referred for further nuclear stress testing.[45] The finding that the implementation of CCTA reduces CC normalcy rates has also been confirmed.[47]

The University of Michigan is currently recruiting patients for a study entitled, "Cost Effectiveness and Utility of Computed Tomography Angiography (CTA) and Cardiac Catheterization." It is hoped that this study will also confirm the CVI registry findings.

CCTA Clinical Practice Integration

Further study in CCTA is indicated and ongoing[48] to answer questions regarding other specific and appropriate applications, the integrative role of CCTA in the context of other well-established diagnostic tests, and the value of CCTA in making clinical patient management decisions. Yet, the present value of CCTA in the evaluation of patients with chest pain and in diagnosing CAD should be judged fairly. Data currently support its use for the diagnosis and prognosis of CAD in low- to intermediate-risk patients with chest pain.

Questions regarding the ability of CCTA to prolong life or improve quality of life[8] are unfair and unrealistic. No diagnostic imaging test has been held to this standard. Furthermore, rigidly comparing CCTA to CC[9] is a flawed scientific analysis. These are independent and complementary tests with different strengths and weaknesses that are used for different purposes. CCTA should not be considered a potential replacement for CC.

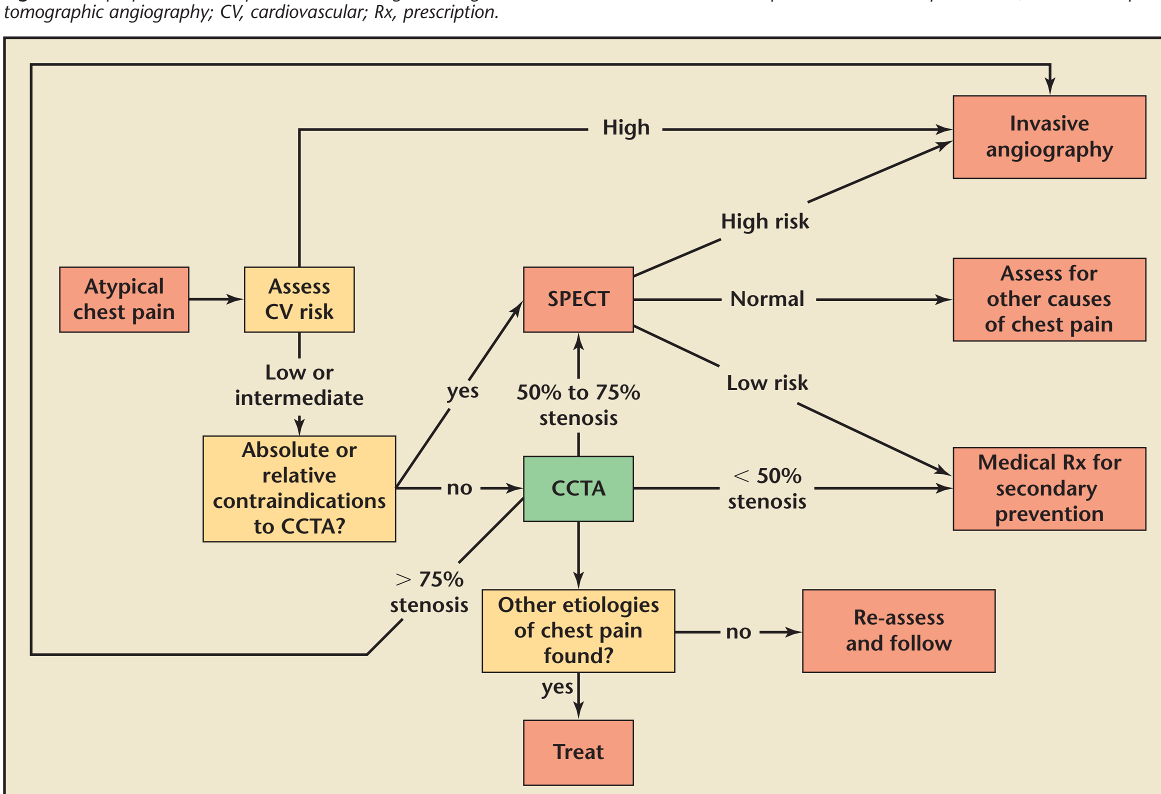
Although the more powerful spatial resolution of CC allows for more accurate grading of coronary stenoses and is not limited by the blooming artifact of coronary calcification, CC without intravascular ultrasound (IVUS) is unable to visualize the actual vessel wall and is merely a "lumen-gram." Furthermore, IVUS is not routinely possible, available, or practical. On the contrary, CCTA may be better able to diagnose atherosclerosis not evident on CC. This strength may in fact add value to patient care by allowing earlier diagnosis and treatment. This claim requires future study.

An important future study to answer remaining critical questions regarding CCTA is in the planning stages. The Functional or Anatomic or Both Functional and Anatomic Testing in Symptomatic Individuals Undergoing Evaluation by CCTA, MPS, or Both: Costs and Clinical Outcomes (FABULOUS) trial is a multicenter, randomized study that will evaluate the clinical utility and cost-effectiveness of an anatomic imaging strategy using CCTA versus a functional imaging strategy using myocardial perfusion imaging in patients without known CAD who present with stable chest pain syndromes.

Conclusion

At present, CCTA may uniquely identify otherwise clinically silent atherosclerosis. In addition, because CCTA may rule in or rule out a plethora of other cardiovascular and noncardiovascular diagnoses, and because stress SPECT imaging has limited ability to diagnose functionally insignificant CAD and other noncardiac ailments, an argument may be made to use CCTA as a first test in the evaluation of chest pain in the low- to intermediate-risk patient (Figure 7). ■

Figure 7. *A proposed clinical practice CCTA integration algorithm for low- to intermediate-risk patients with chest pain. CCTA, cardiac computed tomographic angiography; CV, cardiovascular; Rx, prescription.*



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Main Points

- Advances in cardiac computed tomographic angiography (CCTA) result in reproducible and accurate images of the coronary arteries.
- The power of CCTA lies in its negative predictive value, or its ability to rule out disease.
- The performance of CCTA improves with 64-slice CCTA when compared with 16-slice CCTA, especially with regard to sensitivity.
- CCTA in bypass patients performs very well when it is used to analyze the body of a bypass graft.
- At this time, it is not advisable to routinely use CCTA for the sole purpose of intracoronary stent evaluation.
- Technological advances and patient-specific CCTA protocols have led to marked reductions in CCTA radiation exposure.

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