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SCCT Guidelines

SCCT guidelines on the use of coronary computed tomographic angiography for patients presenting with acute chest pain to the emergency department: A Report of the Society of Cardiovascular Computed Tomography Guidelines Committee

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Preamble

Coronary computed tomography angiography (coronary CTA) is a viable alternative to functional imaging in the assessment of patients presenting with acute chest pain (ACP) to the emergency department (ED). The Society of Cardiovascular Computed Tomography Guidelines Committee was formed to develop recommendations for acquiring, interpreting, and reporting of cardiovascular CT to ensure adequate, safe, and efficient use of this modality. Because of the increasing

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extension of coronary CTA testing for the evaluation of ACP patients, the Committee has been charged with the development of the present document to assist physicians and technologists. These recommendations were produced as an educational tool for practitioners to improve the diagnostic care of patients presenting with ACP to the ED, in the interest of developing systematic standards of practice for coronary CTA based on the best available data or broad expert consensus. Because of the highly variable nature of medical care, and individual and unique patient presentations and circumstances, approaches to patient selection, preparation, protocol selection, interpretation, or reporting that differ from these guidelines may represent an appropriate variation based on a legitimate assessment of an individual patient's needs.

The Society of Cardiovascular Computed Tomography Guidelines Committee makes every effort to avoid any actual or potential conflicts of interest that might arise as a result of an outside relationship or a personal interest of a member of the Guidelines Committee or its Writing Groups. Specifically, all members of both the Guidelines Committee and of Writing Committees are asked to provide disclosure statements of all such relationships that might be perceived as real or potential conflicts of interest relevant to the document topic. The relationships with industry information for Writing Group and Committee members are available in the acknowledgments section of this document. These are reviewed by the Guidelines Committee and will be updated as changes occur.

1. Introduction

Diagnosis and triage of ED patients with suspected acute coronary syndromes (ACS) consumes a large and increasing amount of health care resources. It has been estimated that more than 9 million ED patients with ACP are seen annually in the United States alone, with related health-care costs of $13 to $15 billion.[1,2] The rate of coronary artery disease (CAD) is increasing worldwide, related to the rising prevalence of obesity, diabetes, high-fat dietary changes, and an aging demographic profile.[3] ED crowding per se has been associated with increased adverse outcomes for ACP patients, and consequently, more rapid triage has both health and economic consequences.[4] Therefore, more expeditious safe diagnosis of ACP is a pressing need to increase ED efficiency, contain costs, and improve outcomes. Although the incidence of ACS in patients without a history of cardiovascular events who have negative electrocardiograms (EKGs) and cardiac biomarkers (troponin or creatine-kinase myocardial band) is low (between 1% and 8%),[5–11] the consequences of missing occult ACS are a source of both morbidity and mortality in such patients and significant malpractice litigation.[12,13]

There are many criteria that have been proposed to augment clinical judgment in the assessment of risk of major adverse cardiac events or the likelihood of ACS. These include the Thrombolysis in Myocardial Infarction (TIMI) risk score, Goldman criteria, the ACC/AHA guidelines for management of unstable angina and non–ST-segment elevation of myocardial infarction likelihood of ACS categories, and the HEARTS score)[5,14–16] However, the dilemma that ED physicians face is that although several risk stratification tools[5,6,14,15,17–25]have been developed based on clinical presentation and risk factors, they only provide estimates of the likelihood of ACS with many studies demonstrating that history and physical examination are unreliable in excluding ACS[26–28]. Consequently, the latest AHA scientific statement on testing of low-risk patients presenting to the emergency department with chest pain recommends additional testing in all patients regardless of risk score after initial evaluation.[29] Diagnostic testing includes exercise EKG treadmill testing, rest myocardial perfusion imaging (MPI), stress MPI, stress echocardiography, or anatomic imaging by coronary CTA. Although MPI as a primary test is cost effective because of reduced admission rates,[30] in practice, because of ED overcrowding and the limited numbers of specialized chest pain observation units, evaluation that includes stress testing and/or imaging all too often involves hospital admission to an observation unit and overnight stay to complete the workup. This very expensive occurrence could be avoided by a more efficient early testing strategy that retains diagnostic accuracy while ensuring a <1% miss rate for ACS. Based on the high negative predictive value of coronary CTA for the detection of CAD, and the widespread availability and rapidity of this test, it was hypothesized that if used early after ED presentation, this modality could play a role in delivering more efficient care.[31–37]

1.1. *Evidence supporting the use of coronary CTA for suspected ACS*

Over the past 6 years, a large body of evidence has been published supporting early coronary CTA as a rapid, accurate, safe, and efficient diagnostic strategy for low-intermediate risk ACP patients in the ED.[8–11,38,39]

Before the introduction of coronary CTA for evaluation of ACP patients, a number of accuracy trials compared the results of this modality in non-acute patients with findings on invasive coronary angiography, including, most notably, the multicenter studies: Assessment by Coronary Computed Tomographic Angiography of Individuals Undergoing Invasive Coronary Angiography (ACCURACY) Trial,[31] The Coronary Artery Evaluation Using 64-Row Multidetector Computed Tomography Angiography (CORE-64) study,[33] and the study by Meijboom et al.[40] In these studies, on a per-patient basis, the accuracy of coronary CTA to predict an equal to or greater than 50% stenosis averaged to: 93% sensitivity, 79% specificity, 80% positive predictive value and 93% negative predictive value. These values compared favorably with rest-stress MPI, often considered the standard for noninvasive evaluation of ACP.[41] Based on these encouraging results, a number of single-center studies of ACP patients assessed the ability of coronary CTA to predict either significant coronary ischemia on contemporaneous stress testing and/or the presence of ACS as assessed by a clinical outcomes panel.[42] After these observational trials, data provided by 4 randomized clinical trials compared coronary CTA with "standard-of-care" (SOC) in ACP patients without known CAD who presented with non-ischemic EKG and normal cardiac biomarkers.

The first randomized trial was the single-center 64-STAT trial published in 2009, which randomized 197 patients with TIMI scores ≤2 to coronary CTA or rest-stress MPI.[8] Compared

with rest-stress MPI, coronary CTA resulted in reduced diagnostic time (3.4 hours vs 15.0 hours; $P < .001$) and lowered ED costs ($1586 vs $1872; $P < .001$). Both strategies were safe, without any missed ACS. This was followed in 2011 by the publication of the multicenter CT-STAT trial, which randomized 699 patients at 16 study cites with TIMI scores ≤4 to either coronary CTA (n = 361) or rest-stress MPI (n = 338).[9] Outcomes were similar to 64-STAT, with reduced diagnostic time for coronary CTA (2.9 hours vs 6.3 hours; $P < .001$), lower ED cost of care ($2137 vs $3458; $P < .001$), and no missed ACS. In 2012, two more trials were published. The ROMICAT-II trial randomized 1000 patients to either early coronary CTA or to SOC[43]. Notable differences to the prior randomized studies were that TIMI scores did not limit entry criteria and that the SOC included any available management strategy deemed appropriate by the treating physicians. These choices included EKG treadmill testing, stress echo and stress single-photon emission CT, as well as no further diagnostic testing as an option. Coronary CTA as compared with SOC resulted in a reduced median length of stay (8.6 hours vs 26.7 hours; $P < .001$), time to diagnosis (5.8 hours vs 21.0 hours; $P < .001$), and increase in direct discharges (47% vs 12%; $P < .001$). There were more major adverse cardiac events in the SOC vs the coronary CTA group within 30 days (6 events vs 2 events; $P = .18$), but this difference was not significant. ROMICAT-II also reported costs of care including hospital costs, which were similar between CTA and SOC ($4026 vs $3874). Finally, the ACRIN-PA trial randomized 1370 patients with negative EKG and cardiac biomarkers and TIMI score ≤2 on a 2:1 basis between coronary CTA (908 patients) and SOC (462 patients)[11]. Similar to ROMICAT II, SOC was defined by the attending physicians and included any accepted diagnostic tests and disposition without testing. The primary outcome of the ACRIN trial was safety, and the trial proved that the upper bound of the 95% confidence interval for missed ACS in patients with normal coronary CTA is less than 1%. Overall, ACS rates in these trials varied from 1% to 8%, capturing low to intermediate risk chest pain populations. Most importantly, no patient with ACS was wrongly discharged in the CT arm or in the SOC arm. Patients in the coronary CTA group had a higher rate of direct ED discharge (50% vs 23%) and shorter length of stay (18 hours vs 25 hours). The results confirmed the improved efficiency of coronary CTA without any compromise in patient outcomes. ROMICAT I, an observational study in low to intermediate risk ACP patients, further provided information on long-term safety and established a 2-year warranty period for normal coronary CTA after discharge from the ED.

These studies and other evidence is reflected in the ACCF/SCCT/ACR/AHA/ASE/ASNC/NASCI/SCAI/SCMR 2010 appropriate use criteria for cardiac computed tomography,[44] which designates coronary CTA as appropriate for use in ACP patients with low or intermediate likelihood of ACS. The evidence also prompted inclusion of coronary CTA as a diagnostic option in the American Heart Association (AHA) scientific statement on testing of low-risk patients presenting to the emergency department with chest pain, the American College of Radiology (ACR) appropriateness criteria on chest pain suggestive of acute coronary syndrome, the 2012 ACCF/AHA Focused Update incorporated into the ACCF/AHA 2007 guidelines for the management of patients with unstable angina/non-ST-elevation myocardial infarction, and the United Kingdom National Institute for Health and Clinical Excellence guideline on chest pain of recent onset.[29,44–47]

Although these documents support the use of coronary CTA as a first-line or second-line diagnostic test in ACP patients, there are significant hurdles to clinical implementation of coronary CTA in the ED. There is a paucity of published information on the practical requirements and quality standards needed to organize a successful program. Sufficient local expertise, careful patient preparation, and individualized CT protocol selection are mandatory to ensure adequate diagnostic accuracy. Quality standards to ensure safety and accuracy for suspected ACS patients require additional experience and special staffing above the requirements for a successful coronary CTA program in patients with stable symptoms. These include specifications for equipment, radiology and nursing staff, interpreting physicians, service hours, and interpreting and reporting standards that are particular to the triage of ED patients. Therefore, the Board of Directors of the Society for Cardiovascular Computed Tomography (SCCT) has designated the creation of these guidelines for the use of coronary CTA in the diagnosis of ACP patients with suspected ACS.

2. Site requirements

2.1. *Needs assessment*

A preliminary needs assessment should be undertaken before initiating a new program for evaluation of ACP using coronary CTA (Table 1).[48] This assessment should be conducted jointly by representatives from the emergency, radiology, and cardiology departments. There also should be evidence that sufficient case volume will be likely to maintain expertise, and that the resources are available to achieve rapid high-quality studies, and interpretations will be available during sufficient service hours to be beneficial to patients.

2.2. *Equipment*

Computed tomography scanner equipment should include multidetector scanners with a minimum of 64 detector rows and appropriate cardiac software.[49] Patient-specific tube potential adjustment should be available.[50] At a minimum, scanners should be equipped to perform retrospective spiral acquisitions with EKG-gated tube current modulation. Preferably, lower radiation prospectively triggered axial scanning protocols should be available for most patients.[51–54] Very low dose acquisition modes such as volumetric acquisition or high-pitch scan mode are advantageous but not required. Similarly, the use of iterative reconstruction for dose reduction is advantageous but not required. Image interpretation must be done with three-dimensional postprocessing software capable of displaying reconstructed axial data, multi-planar reconstructions, and maximum intensity projections.[55] Patient safety equipment including advanced cardiovascular life support (ACLS) equipment must be present in the patient preparation and scanner areas.

Table 1 – Site requirements.

Requirement
Equipment
Required
Scanner with 64 detector rows or more, equipped with coronary artery-specific capabilities
ACLS equipment in or in immediate vicinity of scan room
Interpretation platforms with 3D postprocessing software
Prior year coronary CTA minimum volume/y of 300 scans
CT laboratory accreditation
Recommended
Scanner equipped to perform prospective-triggered (sequential) scanning in appropriate patients for radiation dose reduction and other radiation dose reduction capabilities required to achieve target radiation dose levels
Quality assurance program goals
A) Achieving a nondiagnostic scan proportion ≤5%
B) Median radiation dose within target reference level established by the Society for Cardiovascular Computed Tomography guidelines on radiation dose and dose-optimization strategies in cardiovascular CT
C) Quarterly review of coronary CTA interpretation compared with invasive angiography achieving 75% accuracy
Staffing
Required
At least 1 technologist with prior volume experience of at least 100 coronary CTA scans. Technologists performing scans without the immediate proximity of an ACLS-certified nurse must have current ACLS certification
Properly trained ACLS-certified nursing staff for beta-blocker premedication of patients
Rapid response team and/or ACLS-certified physician available for prompt response to urgent or emergent complications
Scanner operation, availability, and staffing-service hours must satisfy ED minimum requirements

3D, 3 dimensional; ACLS, advanced cardiovascular life support; CTA, CT angiography; ED, emergency department.

2.3. *Staff*

ED programs should be initiated only at sites with sufficient experience and case volume, with a recommended minimum of 300 cases in the previous year. At least 1 technologist with prior volume experience of at least 100 coronary artery scans is required to initiate the program. Technologists who perform scans without the immediate proximity of an ACLS-certified nurse must have current ACLS certification. Properly trained ACLS-certified nursing staff should supervise premedication of patients. A rapid response team and/or an ACLS-certified physician must be readily available for prompt response to urgent or emergent complications. The scanner and staffing service hours must satisfy ED minimum requirements.

2.4. *Quality assurance*

A quality assurance program is recommended, with quality targets including: a diagnostic-quality scan rate of ≥95%, a quarterly median radiation dose rate within the reference level (currently, 12 mSv, based on the most recent guideline) established by the SCCT guidelines on radiation dose and dose-optimization strategies in cardiovascular CT, and a quarterly comparative review of cases with both coronary CTA and invasive angiography that demonstrates a median accuracy of at least 75% per-patient accuracy.[51]

2.5. *Implementation*

It is important to implement an algorithm for appropriate triage of patients in the ED using well-established clinical pathways.[56] This is a critical step for successful implementation of coronary CTA in the ED, as well as to clearly distinguish eligibility of patients for alternative imaging modalities, such as functional imaging. Second, and also of paramount importance, is the involvement of a multidisciplinary team including ED physicians, radiologists, cardiologists, and hospitalists who agree to implement and to follow-up the chest pain algorithm protocol. Finally, support from hospital administration and nursing are also key factors, such that all parties are in agreement and the protocol is patient-centric.

3. Interpreting physician requirements

Because of the severe health consequences of missed ACS, additional physician experience is required for physicians reading ED scans beyond that required to begin reading scans in stable patients (Table 2). Certification Board of Cardiovascular Computed Tomography certification or ACR Board certification “Advanced proficiency in Cardiac CT” or dedicated fellowship training in advanced cardiac imaging is recommended. The SCCT suggests that program initiation requires that the program director has a minimum of 2 years of clinical experience and/or at least 300 prior coronary CTA scan interpretations.[57,58] All interpreting physicians must attain and maintain level-2 coronary CTA certification or the equivalent. In addition, all physicians must be experienced in the best-practice patient preparation and protocol selection methods pertinent to the particular scanner model in use. Interpreting physicians must be available in person or by telephone to consult with nurses and technologists about patient preparation or protocol selection before the scan. A physician qualified by the institution must interpret all noncardiac anatomy on all scans. The interpreting physician may be off-site if an ACLS-certified physician is immediately available to the patient.

Table 2 – Interpreting physician requirements.

Physician requirement
Required
At least 1 physician with a minimum of 2 years of clinical experience and/or 300 scan interpretations of coronary CTA
All other physicians must maintain level-2 coronary CTA certification or equivalent
Interpreting physicians must be trained in the best-practice protocol selection of the scanner(s) in use
Physicians must be promptly available in person or by phone for consultation about patient preparation and scan protocoling
A qualified physician must interpret the noncardiac anatomy on all scans either as the primary reader or as a consulting physician
Recommended
CBCCT certification or ACR Board certification or dedicated fellowship training in advanced cardiac imaging

ACR, American College of Radiology; CTA, CT angiography; CBCCT, Certification Board of Cardiovascular Computed Tomography.

4. Patient selection

4.1. *Pretest likelihood of ACS*

In general, patient selection is guided by the patient's history, clinical presentation, electrocardiography (ECG), and initial biomarker assessment (Table 3). Patients suitable for coronary CTA should have reasonable clinical suspicion of ACS, but at the time of coronary CTA should have no definite objective evidence of ACS on EKG or myocardial necrosis by biomarkers. A careful history and physical examination should precede any cardiac testing, to exclude alternative noncoronary diagnoses and to help define the pretest likelihood of ACS. Preliminary test findings (eg, EKG, cardiac biomarkers, chest x-rays, and so forth) to permit calculation of risk stratification tools such as

Table 3 – Patient selection.

Appropriate indications
Acute chest pain patients with clinically suspected coronary ischemia
EKG negative or indeterminate for myocardial ischemia
Low-intermediate pretest likelihood by risk stratification tools, for example, TIMI 0–2 risk score (low) or 3–4 (intermediate) risk
Equivocal or inadequate previous functional testing during index ED or within previous 6 months
Uncertain Indications
High clinical likelihood of ACS by clinical assessment and standard risk criteria (eg, TIMI score >4)
Previously known coronary artery disease
a. Previously documented myocardial infarction
b. Previously documented ischemia by stress testing or CAD on invasive angiography
c. Previous coronary revascularization
d. Known calcium score ≥400
Relative contraindications
Alternative testing should be preferred in these cases: history of allergic reaction to iodinated contrast without history of anaphylaxis or allergic reaction after adequate steroid/antihistamine preparation
GFR <60
Previous substantial volume of contrast within 24 h (this will vary with GFR)
Factors leading to potentially non-diagnostic scans; specifics will vary with scanner technology and site capabilities
e. Heart rate > site maximum for reliably diagnostic scans after beta blockers
f. Contraindications to beta blockers and inadequate HR control
g. Atrial fibrillation or other markedly irregular rhythm
h. BMI >39 kg/m^2
Absolute contraindications
Acute coronary syndromes—definite
GFR <30 unless on chronic dialysis, or evidence of ATN
Previous anaphylaxis after iodinated contrast administration
Previous episode of contrast allergy after adequate steroid/antihistamine preparation
Inability to cooperate, including inability to raise arms
Pregnancy or uncertain pregnancy status in premenopausal women
Additional considerations in patient selection
Radiation-sensitive populations, for example, gender and age
Previous radiation exposure history
Need for thoracic CT imaging, for example, triple or double r/o meeting valid diagnostic criteria such as D-dimer. These factors may predispose use of coronary CTA as opposed to stress testing
Other intra-thoracic pathology suspected such as pericardial disease for which thoracic CT may be required
Inability to perform alternative diagnostic strategies in the presence of relative contraindications

ACS, acute coronary syndrome; ATN, acute tubular necrosis; CAD, coronary artery disease; CTA, CT angiography; ED, emergency department; EKG, electrocardiogram; GFR, glomerular filtration rate; r/o, rule out; TIMI, thrombolysis in myocardial infarction risk score.

the TIMI risk score should be sufficiently completed to be included in this decision. To be consistent with the patient selection criteria used in some of the previously cited trials, in this document the pretest likelihood of ACS in these guidelines will be classified by the TIMI score. However, it should be emphasized that physician judgment should not be preempted by numerical scoring systems in the assessment of an individual patient. Physician judgment is also of value in assessing the likelihood that coronary CTA is likely to be of diagnostic quality, based on clinical factors such as body mass index, relative or absolute contraindications to beta blocker use, and age.[59] Additionally, patients with known CAD, prior myocardial infarction (MI), or stents may not be not well suited for testing with coronary CTA, and such patients were not included in the 4 previously cited randomized cited trials.[8–11,60]

4.2. *General safety and diagnostic quality considerations*

The principal safety considerations for coronary CTA include radiation exposure, allergic reactions to iodinated contrast agents, and contrast-induced nephropathy. An overview of absolute and relative contraindications to coronary CTA is provided in Table 3. A "patient-centered" approach to radiation risk should be adopted[61]. The use of any exposure to radiation should always be weighed against the potential risk of cancer, according to the "as low as reasonably achievable" principle. For example, increased radiation sensitivity in premenopausal women or younger patients or patient characteristics known to impair image quality (ie, inability to take beta blockers, lack of cooperation, or high body mass index) may favor alternative test strategies. Ideally, consideration of alternative modalities would also include a history of the patient's cumulative radiation exposure.[62] Currently, there is no systematic way to verify this exposure in the United States, but quantitative systems have been proposed. Although high body mass index generally adversely affects coronary CTA image quality, that is also true of alternative modalities, and ultimately, clinical judgment by the referring physician is required for optimal test selection.

4.3. *Clinical considerations*

To choose the optimal diagnostic test in a given patient, it is important to understand that coronary CTA provides information about coronary plaque morphology and stenosis. It is worth pointing out that newer CT technology may also permit capture of regional and global left ventricular (LV) function and wall motion at low doses, which has been shown incremental to coronary anatomy for the diagnosis of ACS. In contrast, functional tests including EKG-only stress testing or stress testing with use of imaging such as echocardiography or MPI can demonstrate regions of myocardial ischemia due to inadequate coronary flow reserve. There are advantages and disadvantages to each approach. Coronary CTA is the most sensitive noninvasive test available to detect CAD, including nonobstructive plaque that is not detectable by stress testing[32,63] as well as obstructive CAD. Coronary CTA is most effective in patients with a low-intermediate pretest likelihood of ACS. Only about 50% of these patients have CAD, and in the cited trials, no patient without coronary CTA evidence of CAD developed ACS. It is in this group of patients that coronary CTA is most efficient. Approximately 5% to 15% of ACP patients eligible for coronary CTA have obstructive CAD. Most patients with ACS demonstrate coronary stenosis >70% on coronary CTA. The likelihood of ACS is also increased in patients with moderate CAD (50%–70% stenosis), but in these patients additional functional testing should be considered.[64]

In patients with high pretest likelihood of ACS, the multisociety appropriate use guidelines classify the appropriateness of coronary CTA as "uncertain". In these patients, there is an increased likelihood that coronary CTA will not be definitive, and additional functional testing or admission will be required. However, clinical judgment should be used in individual patients.

In most patients with previously known CAD, as established by prior MI, invasive coronary angiography, or functional testing with definite ischemia, coronary CTA will confirm the presence of CAD lesions but cannot definitively diagnose ischemia, especially in intermediate grade stenosis (25%–49%). In general, further functional testing or admission will be required unless the original diagnosis was in error. Thus, the presence of known CAD is a relative contraindication to coronary CTA. Patients with a high likelihood of ACS have a higher incidence of such lesions, often leading to subsequent functional imaging; therefore, coronary CTA may be less efficient as a primary test in this group.

Although known CAD, prior MI, or coronary revascularization is a relative contraindication to coronary CTA in ACP, in some cases, as determined by an experienced physician, there may be a carefully defined circumstance that supports the use of coronary CTA.[65] For example, a referring cardiologist may know that a particular patient has a previous proximal stent and little if any other CAD. The establishment of stent patency without severe progression in other coronary segments may provide effective triage for that patient. Although the accuracy of coronary CTA evaluation of stenosis severity may be reduced due to calcification, metallic stents, or surgical clips, evaluation of proximal stents with a diameter ≥3.0 mm has been reported to have a higher accuracy rate.[60] The presence of dense focal calcification from previous coronary calcium scoring may also weigh against the decision to use coronary CTA. Although establishing a specific level of Agatston score that precludes the use of coronary CTA has not been recommended in the SCCT guidelines for performing, interpreting, and reporting coronary CTA, these may be established at individual institutions.[49,55]

The use of coronary CTA in patients with definite ACS is inappropriate. Patients should be immediately triaged by established guidelines. Coronary CTA results in unnecessary delay and adds unnecessary additional exposure to ionizing radiation and iodinated contrast.

Patients with nondiagnostic or equivocal stress test findings may benefit from coronary CTA, as a negative CTA may obviate the need for admission or invasive angiography.

4.4. *Noncoronary thoracic diagnoses*

In most clinical institutions, in addition to a cardiac-specific field of view, a full field of view is reconstructed that

Table 4 – Sample institutional diagnostic pathway.

Risk category	Suspected diagnosis	Appropriate diagnostic strategy
Level 5	STEMI	ICA
Level 4	NSTEMI, UAP	ICA
Level 3	High Risk (e.g., TIMI >4)	Functional assessment and/or admission
Level 1–2	Low-intermediate risk (eg, TIMI 0–4)	Coronary CTA or functional assessment
Level 0	Non-cardiac chest pain	CXR, chest CTA (PE, aortic dissection), GI work-up, and so forth

CTA, CT angiography; CXR, chest radiography; GI, gastrointestinal; ICA, invasive coronary angiography; NSTEMI, non–ST segment elevation myocardial infarction; PE, pulmonary embolism; STEMI, ST elevation myocardial infarction; TIMI, thrombolysis in myocardial infarction risk score.

incorporates the full scan length. In general, this extends from the middle of the main pulmonary artery to the dome of the diaphragm to assess extracardiac findings.[66,67] This encompasses roughly one-half to two-thirds of the thoracic contents, yielding high-resolution contrast-enhanced images of the lungs, aorta, pulmonary arteries, noncoronary cardiac structures, and the hilum. Although most ACP symptoms are not attributable to coronary ischemia, visualization of these additional thoracic structures rarely identifies an alternative explanation for the chest pain, and the vast majority of noncardiac findings (>80%) are pulmonary nodules that are not related to the patient's pain.

In addition, dedicated coronary CTA leaves the pulmonary arteries generally poorly opacified because contrast administration is timed to optimize contrast in the coronaries, and saline is commonly used to reduce contrast intensity in the right heart to permit better evaluation of the right coronary artery. Despite these limitations, all coronary CTA scans should be examined thoroughly for noncardiac and noncoronary cardiac diagnoses, such as pleural and pericardial effusions and pulmonary parenchymal and aortic disease. Although the previously mentioned limitations apply to pulmonary emboli in routine coronary CTA scans, centrally located pulmonary emboli may be recognizable, and right ventricular dilation can also be readily discerned.

In selected patients, there may be more than 1 life-threatening clinical suspicion; for example, when a patient with multiple cardiac risk factors also has a positive D-dimer test suggesting possible pulmonary embolism. Technically, CT technology permits increasing the field of view to include the entire thorax, and use one of several techniques can sequentially opacify the aorta, pulmonary arteries, and coronary arteries. This so-called "triple rule-out" CT protocol may be used to exclude disease of all 3 vascular beds. However, positive extracardiac findings are rare, and the examination comes with increased radiation and contrast dose. There is no evidence that triple rule-out is efficient, and hence, this protocol should be reserved for selected patients in whom the additional risks are clearly justified.[68–70]

5. Clinical scenarios

These patient scenarios are provided to illustrate a sample diagnostic pathway that integrates appropriate coronary CTA use with standard care for patients with suspected or definite ACS (Table 4). Institutional practice will vary and all management decisions should be individualized for patients based on physicians' clinical judgment.

5.1. *Low risk—level 1*

A 55-year-old woman presents with exertional dyspnea and back pain. The EKG is normal and troponin levels are within normal limits. She is hypertensive on examination and has a history of hyperlipidemia.

The indications noted are as follows:

- TIMI score: 0
- ACCF/AHA category: low
- HEARTS3 ACS likelihood: 0%

According to the multisociety appropriate use criteria, coronary CTA is appropriate in this patient in the absence of clinical contraindications.[44]

5.2. *Intermediate risk—level 2*

A 45-year-old man presents with 3 nonexertional chest pain episodes in the past day. The EKG shows nonspecific ST-T changes without serial changes, and troponin levels are within normal limits. His father had an acute MI at the age of 54. He has been taking 1 aspirin a day.

The indications noted are as follows:

- TIMI score: 2.
- ACCF/AHA category: Intermediate.
- HEARTS3 ACS likelihood: 4.6%

According to the multisociety appropriate use criteria, coronary CTA is appropriate in this patient in the absence of clinical contraindications.

5.3. *High risk—level 3*

A 70-year-old woman presents with new episodes of exertional chest pressure and left arm pain during the past 48 hours. She has a history of smoking, hypertension, diabetes, and takes an aspirin daily for peripheral vascular disease. The EKG demonstrates < 0.5 mm of ST depression without serial changes, and troponin levels are within normal limits.

Table 5 – Patient preparation: principles.

Required
Establishment of institution-specific guidelines for diagnostic heart rate and rhythm based on scanner technology and staff capability
Establishment of institutional guidelines for safe patient-specific beta blocker dose protocol, based on staff availability, capability, and patient monitoring
Verification of acceptable GFR and negative pregnancy testing as appropriate
Ability to establish intravenous access capable of administration of contrast at flow rates required for coronary CTA
Patient interview to determine ability to follow instructions, educate about breath holding and other aspects of procedure
Measurement of baseline vital signs
Administration of oral beta blockers at institutionally approved dose ranges if baseline heart rate does not fall into approved range. Intravenous beta blockers may be supplemental to or alternative to oral route depending on institutional guidelines
Repeat vital signs measurement after 30–60 minutes
If heart rate not in acceptable range, consultation with supervising physician for additional beta blocker dosage
Nitroglycerin before scan unless blood pressure out of range or history of prior adverse reaction, or other contraindications to its use
In case of GFR <60 h, 4 h prescan hydration or alternative preparation according to institutional guidelines
In case of previous mild-moderate contrast allergy, provided clinical decision is made against alternative testing, antihistamine/corticosteroid preparation over 6–12 h according to institutional guidelines
Recommended
Intravenous saline for BP support before and during beta blocker dosage if necessary to achieve target heart rate if no contraindication is present

BP, blood pressure; CTA, CT angiography; GFR, glomerular filtration rate.

The indications noted are as follows:

- TIMI score: 4.
- ACCF/AHA category: Intermediate.
- HEARTS3 ACS likelihood: 35.3%

According to the multisociety appropriate use criteria, it is uncertain whether use of coronary CTA is appropriate in this patient.

5.4. *Unstable angina—level 4*

A 50-year-old man presents with several hours of episodic chest pain at rest accompanied by nausea. The baseline EKG shows no abnormality, but with chest pain, there is 1 mm of down-sloping ST depression that normalizes with nitroglycerin. The baseline troponin level is greater than institutional limits of normal and increases slightly after 4 hours.

This patient fulfills diagnostic criteria for definite unstable angina/non–ST-segment elevation myocardial infarction, and the use of coronary CTA is inappropriate.

5.5. *ST-Elevation acute myocardial infarction—level 5*

The use of coronary CTA is absolutely contraindicated in ST-segment elevation myocardial infarction as defined by established criteria. Such patients require urgent invasive evaluation and management or thrombolysis, and use of coronary CTA is inappropriate.

6. Patient preparation

Achieving high diagnostic accuracy with the lowest possible radiation dose requires careful preparation of coronary CTA patients. CT imaging is sensitive to motion, requiring slow steady heart rates and patient cooperation. Higher heart rates require scan protocols that are less sensitive to movement, such as retrospective EKG-gated scan protocols, but these result in higher radiation doses. The precise targets for adequate scans depend on the scanner technology available. The essential steps in preparing patients for coronary CTA include evaluation, education, medication, and re-evaluation after premedication.[71] Detailed principles of patient preparation guidelines are listed in Table 5. A sample institutional guideline is presented in Table 6. Table 6 is an example and is not meant to substitute for sound clinical judgment. It should be reviewed in light of the scanner equipment available and institutional experience and preferences.

6.1. *Patient evaluation*

Patients must be evaluated by the staff to ensure that no absolute contraindications exist to the examination. If uncertain, the staff should confer with the attending physician. It should be clear that the patient understands the nature of the examination and can cooperate with breath-holding instructions. Baseline vital signs should be used to design a prescan medication protocol to achieve heart-rate targets based on the scanner model to be used. Staff should ascertain the patient's previous medications. If the baseline heart rate is within target range, a mild stress, for example, 30 seconds of hard hand-grip on a towel, may be considered to ensure heart rate does not rise unduly.

6.2. *Patient education*

Patients should be fully informed about the nature of the examination, its objectives, possible risks including radiation dose, their required cooperation, and the sensations they are likely to feel. It is suggested that radiation dose be compared with annual background dose (approximately 3 mSv in the United States). They should be given a chance to request an alternative diagnostic strategy if they feel unable or unwilling to proceed. This educational process should be repeated after premedication, just before scanning, to be sure the patient

Table 6 – Patient preparation: sample institutional guidelines.

A. Recommendation for physicians/staff
   1. Ensure that the scan is appropriate for the patient's symptoms and presentation
   2. Select patients based on pretest likelihood of ACS which would place them in a low-to-intermediate risk category based on TIMI risk score[1] or equivalent and clinical judgment
   3. Prescribe beta blockers if appropriate, with the intent to achieve a target heart rate of ≤60 beats/min
   4. Evaluate renal function and prescribe hydration protocol when indicated. Prescribe medications to suppress iodinated contrast allergy when indicated
B. Nursing Assessment
   1. Describe test including contraindications, position, breath hold, sensations and medications. Assess ability and willingness to cooperate. Evaluate for contraindications
   2. Assess heart rate variability and blood pressure, and effects of breath hold on heart rate
   3. Administer beta-blockers to achieve target heart rate (if no contraindication such as reactive airway disease, severe aortic stenosis, and so forth)
C. Administration of beta-blockers
   1. Baseline heart rates >60 beats/min, blood pressure >90 mm Hg systolic, body mass index >18 kg/m^2: Administer 100 mg of oral metoprolol or comparable dose equivalent, 30 min to 1 h before the procedure, or comparable intravenous doses with telemetric monitoring
   2. Baseline heart rates >55 beats/min, but less than 65 beats/min, blood pressure >90 mm Hg: Administer 50 mg of oral metoprolol (or other immediate-release oral beta blocker) to block heart rate acceleration during scan, or comparable intravenous doses with telemetric monitoring
   3. Consult with physician if heart rate cannot be achieved for possible additional oral or intravenous beta blockers
D. Nitroglycerin administration: Systolic blood pressure is >100 mm Hg, use 0.4 mg of sublingual nitroglycerin. For systolic <100 mg, consult with physician. Omit nitroglycerin in patients with contraindications (eg, aortic stenosis, intake of phosphodiesterase inhibitors in preceding 12 h, and so forth)

ACS, acute coronary syndrome; TIMI, thrombolysis in myocardial infarction risk score.

remembers the instructions on breath-holding and is prepared for the sensations likely to occur from nitroglycerin and contrast administration.

6.3. *Patient premedication*

A vast majority of patients require premedication with beta-blockers, and prescan nitroglycerin should be standard unless specific contraindications exist. A detailed example of premedication orders is listed in Table 5. Institutional protocols will vary depending on target heart rates required by the scanner model to be used; preferably, a set of standardized orders should be made available to the staff.

7. Scan protocol selection

Scan acquisitions should be consistent with SCCT guidelines for performance of coronary computed tomography[49] (Tables 7 and 8). In planning a coronary CTA, knowledge of

Table 7 – Scan protocol selection: principles.

Required
1. Scan acquisition should be consistent with SCCT guidelines for performing coronary CTA[49].
2. Institutional scan protocol guidelines should be established and staff trained in routine scan protocol selection, based on scanner hardware and software, as well as staff capabilities. Physicians must be readily available to answer questions on protocol selection
3. Scan protocols should prioritize achievement of diagnostic scan quality, consistent with the lowest achievable radiation dose based on individual patient characteristics
4. Protocol selection should consider achieved heart rate and rhythm after maximal patient preparation, patient body habitus including body mass index, weight, and thoracic diameter
5. Tube potential should be customized by BMI. Preference should be given to the use of 100 kV tube potential for patient BMI ≤30 kg/m^2
6. Tube current should be customized using an automated current selection algorithm based on scanned body profile (eg, topogram) if available in scanner model, or a weight-based chart
7. Scan mode should be customized by heart rate and rhythm, choosing the lowest dose mode based on patient characteristic and scanner model
   a. Preference should be given to the use of prospective EKG-triggered acquisition for radiation dose reduction if consistent with heart rate and rhythm. Acceptable motion-free heart rate range depends on scanner
   b. Retrospective EKG-gated acquisition should be used as needed when necessary to achieve a high likelihood of diagnostic scans. If retrospective scanning is used, EKG-gated tube current modulation should used if heart rhythm permits. Depending on scanner, heart rates >65 may require retrospective gating with multiple reconstructions, as does significant rhythm irregularity

Recommended
1. Newer low-dose scan modes (eg, wide-detector prospective or high-pitch spiral acquisition) should be used with low heart rates on advanced scanners, if consistent with diagnostic image quality
2. If available, iterative reconstruction should be used to reduce radiation dose and improve quality, based on an established institutional algorithm

BMI, body mass index; CTA, CT angiography; EKG, electrocardiogram; SCCT, Society of Cardiovascular Computed Tomography.

Table 8 – Protocol selection: sample institutional guidelines.

Scan FOV
FOV should be consistently restricted to midpulmonary artery to the diaphragm
Extended FOV "triple rule out" scans should be limited to patients with clinical likelihood of either a pulmonary embolus or aortic dissection based on generally accepted diagnostic criteria
Tube current
Tube current should be adjusted by automated current adjustment mode, unless patient BMI $\geq$40 kg/m^2. For these patients, contact supervising physician for protocol instructions on tube current, tube voltage, and scan mode
Tube potential
Use tube potential of 100 kVp in patients with a body weight of 85 kg or less and a BMI $<$30 kg/m^2. Individual institutions may adjust this level depending on scanner model or experience (eg,100 kV under 100 kg may be possible)
In patients with BMI 30–40 kg/m^2, use 120 kVp
In patients with BMI $<$18 kg/m^2, tube potential may further be reduced to 80 kVp, subject to physician discretion
In patients with BMI $\geq$40 kg/m^2, physician may consider 140 kVp, depending on age, gender, and body mass distribution
Iterative reconstruction
Iterative reconstruction should be considered if available to reduce tube current
Prospectively triggered axial (sequential) scanning
Use in patients with stable sinus rhythm below the target heart rate (typically 65 beats/min, but may be adapted according to scanner model and local protocols)
Retrospectively gated helical scanning
Use in patients with heart rates higher than prospective-triggered target range or significantly irregular rhythm. Supervising physician should be called for scan protocoling on all patients in atrial fibrillation
Acquisition window width
• Heart rate $<$65 beats/min: 65%–75%
• Heart rate 66–72 beats/min: 60%–80%
• Heart rate $>$72 beats/min: 35%–80%
Tube current modulation
Highly variable heart rates or atrial fibrillation may preclude the use of dose modulation
Tube output outside of the ECG modulation window. The lowest available tube current outside the window should be used (eg, 5% of maximal)
High-pitch helical scanning
Use in patients with heart rates $<$60 beats/min and BMI $<$30 kg/m^2. Scan mode should be set to auto-reject variable heart rate
Imaging of the aorta, pulmonary, and coronary arteries in a single procedure: The "triple rule-out scan"[68,77,96,97]
Patients should meet standard ED criteria for significant risk of potential pulmonary embolism or aortic dissection, as this procedure entails increased radiation dose (25%–50%) and has a very low yield in general ACP population

ACP, acute chest pain; BMI, body mass index; ECG, electrocardiogram; ED, emergency department; FOV, field of view.

the indications for the scan and of patient characteristics is of paramount importance. The indication of possible ACS has specific requirements. For example, although noncontrast calcium scoring scan provide useful data, there is a significant proportion of patients with zero calcium scores who have ACS and >50% stenosis due to noncalcified plaque.[72–75] For this reason, in patients undergoing coronary CT for exclusion of ACS, angiography must always be used, but calcium scoring is optional.

At the present stage of development, optimizing coronary CTA protocols is labor intensive. An important principle is that protocols should provide the highest diagnostic quality with the lowest radiation dose (Table 7). A carefully thought out institutional algorithm for protocol selection will allow management of most patients; however, physicians must be available to assist what can be difficult decisions in individual patients (Table 8). The main patient factors to consider are type of scan (ie, coronaries only, "triple rule out", evaluation of bypass grafts, and so forth), heart rate, age, and body mass index of the patient.[52]

One consideration in every patient is patient-specific protocoling to minimize radiation dose while still achieving a diagnostic result in the entire coronary tree.[76] This results in modification of scan length, timing and infusion rate of the contrast bolus, and alteration of tube potential (voltage) and tube current. Scan length can be determined in 2 ways: by the initial topogram or by the noncontrast calcium scoring CT scan. Scan length is decreased as much as possible, to include the heart from above the level of the highest coronary artery (often the left anterior descending) to below the level of the posterior descending artery. Scan length is increased as necessary for evaluation of bypass grafts (to include origin of the left internal mammary artery) or the aorta and pulmonary arteries (in triple rule-out scans)[77,78] Routine use of 100-kV tube potential is generally possible in patients with a body mass index $\leq$30 kg/m^2 and is the most important dose reduction method, apart from scan mode.[79–81] It should be noted that radiation dose varies approximately as the square of the change in tube potential, as opposed to linearly with tube current or scan length. On the other hand, very high body mass ($\geq$40 kg/m^2) may require a higher tube potential (140 kV) to yield diagnostic quality. In such cases, the supervising physician should be involved in decision making about this choice. In adjusting tube current to body habitus, many current scan models provide automated adjustment from a profile taken from the topogram or by other means. If iterative reconstruction is available, institutional standards may include reduction of tube current across the board.[82–84] This may need to be changed for individual decision making, for example, due to obesity.

Every attempt should be made to use low-dose prospectively triggered (sequential) scan modes routinely.[85] A sample

protocol selection guide is listed in Table 8. If retrospectively gated scans are necessary (generally because of high or irregular heart rates), ECG-gated tube current modulation should always be used unless specific clinical situations exist. Very low-dose newer scan modes such as high-pitch or wide-detector volumetric scans should be used, if available, in patients meeting standards for target heart rates and body habitus.[86–95]

A high iodine concentration contrast agent is infused at a high flow rate (5–7 mL/s) to optimize coronary imaging. The volume of contrast needed is determined by the scan duration. Contrast administration protocols vary among institutions, with use of contrast injection followed by saline chaser, contrast injection followed by saline diluted with contrast or simultaneous contrast and saline injection. Scanning is initiated either by a "timing-bolus" method (in which a test bolus is injected and time to opacification of the aortic root determines the contrast injection), or a "bolus-tracking" method (in which the scan begins automatically when a preset CT number density threshold is reached in the aortic root). When scan quality is deemed adequate, the patient is taken off the scanner table and discharged from the laboratory after an observation period to insure hemodynamic and clinical stability before transfer back to the ED.

A single procedure ("triple rule-out") to exclude CAD, pulmonary embolism, and aortic dissection requires additional radiation (an increase of 25%–50% over coronary CTA alone) because of an extended scan length, as well as a larger dose of contrast. Studies have demonstrated that the incidence of pulmonary embolism or dissection in patients undergoing this procedure in registry data is very low, and consequently, satisfaction of clinical evidence standards for pulmonary angiography or aortography should be present to justify a combined procedure. Depending on scanner model, this protocol can be done with an extended dye infusion to maintain pulmonary artery opacification (using a coronary rate infusion, eg, 5 mL/s) followed by a reduced rate (3 mL/s) or a late-phase infusion of reduced contrast concentration. Alternatively, for example, if high-pitch scan mode is available, a single bolus may be imaged twice, first timed to the pulmonary artery and then subsequently to the aorta.

8. Interpreting and reporting scans for suspected ACS

The interpretation and reporting of coronary CTA should conform to the SCCT guidelines for interpretation and reporting of coronary CTA[55] (Tables 9 and 10). In addition, there are particular considerations pertinent to the clinical needs of the ACP patient. The presentation with a potentially life-threatening syndrome requires expedited completion of

Table 9 – Interpretation and reporting.

Required
Interpretation and reporting should be consistent with SCCT guidelines
Scans should be reconstructed immediately after acquisition
Physicians should be notified immediately of scans for suspected ACS
Scans should be interpreted within 60 min of reconstruction
Abnormal scans must be reported verbally to referring physician
Lesion location should be identified by the 18-segment SCCT model
Lesion stenosis should be reported quantitatively according to SCCT guidelines
Recommended Stenosis Grading
0—Normal: absence of plaque and no luminal stenosis
1—Minimal: plaque with <25% stenosis
2—Mild: 25%–49% stenosis
3—Moderate: 50%–69% stenosis
4—Severe: 70%–99% stenosis
5—Occluded
Optional Stenosis Grading
0—Normal: absence of plaque and no luminal stenosis
1—Mild: plaque present, <39% stenosis
2—Moderate: 40%–69% stenosis
3—Severe: 70%–99% stenosis
4—Occluded
Extent of disease should be further qualified by identification of plaque type, that is, calcified, noncalcified, or mixed noncalcified/calcified. Additionally, positive remodeling or other features of lesion complexity may be described
Noncoronary cardiac findings should be included in the body of the report on coronary findings
Important noncardiac or noncoronary cardiac findings (pulmonary embolism, aortic dissection) should be reported immediately to allow expedited patient triage
Recommended
All scans including normal studies should be reported verbally to ED staff to expedite triage
Scan reports should be incorporated immediately into an electronic medical record
Management recommendations of abnormal scans should be discussed directly with the referring physician to facilitate understanding of coronary CTA findings
Development of institution-specific management guidelines is recommended

ACS, acute coronary syndrome; CTA, CT angiography; ED, emergency department; SCCT, Society of Cardiovascular Computed Tomography.

Table 10 – Sample management recommendations to ED physicians.

Degree of maximal coronary stenosis	Management recommendation
0%–25%	ACS unlikely; discharge is reasonable. Follow-up for minimal CAD at physician discretion
26%–49%	ACS unlikely; discharge is reasonable. Outpatient follow-up recommended for preventive measures
50%–69%	ACS possible; further evaluation indicated before discharge
>70%	ACS likely; admit for further evaluation

ACS, acute coronary syndrome, CAD, coronary artery disease.

the acquisition, reconstruction, interpretation, and reporting of studies in these patients, and therefore, these should be given priority over non-acute cases. In addition, any potentially life-threatening findings must be communicated urgently and directly to ED staff. To expedite patient flow in the ED, it is also recommended that all emergency scans be reported verbally to the ED staff, if feasible. In addition, all noncardiac findings must be reported, including, but not limited to, life-threatening findings such as aortic dissection and acute pulmonary emboli.[46,66,68,97–99]

8.1. *Interpretation*

All segments of the coronary tree should be analyzed using the 18-segment SCCT model.[55] Lesions should be characterized by segment, and all segments should be analyzed. Analysis of stenosis grade, plaque morphology, and plaque composition should be performed using axial images and multiplanar reconstructions of the minimum available slice thickness.[100] Maximal intensity projections and curved planar reconstructions are valuable adjuncts to the previously mentioned techniques. Volume-rendered reconstructions should not be used for interpretation. Lesions should be analyzed for the degree of stenosis severity, which is generally expressed as a maximal diameter stenosis in percent using the SCCT guideline scales. Lesion characteristics beyond stenosis should be analyzed, including total plaque burden, degree and pattern of calcification, plaque composition such as highly lucent plaque, and plaque morphology, including positive remodeling, ulceration, intramural dye penetration, overhanging edges, and other signs of lesion complexity.

Diagnostic uncertainty regarding stenosis severity should be resolved by viewing multiple phases, if available.[101] If deemed necessary, the interpreting physician should request that the staff prepare additional reconstructions; these are always available on retrospectively gated acquisitions. When prospective gating is used, acquisition of more than the minimum window (eg, acquisition at 65%, 70%, and 75% of R-R cycle) will allow reconstruction of 2 to 3 phases. Strict attention should be paid to the confounding effects of coronary calcium. Heavily calcified segments without clear residual lumen should be classified as nondiagnostic for stenosis grading, but high-grade stenosis cannot be excluded. Routine precoronary CTA noncontrast calcium scoring scans are not required in every case. When such scans are available, and extensive dense calcifications are present, supervising physicians may defer performing coronary CTA until further discussion with referring physicians and may recommend alternative noninvasive testing.

Extracoronary cardiac evaluation should include examination of cardiac morphology and the pericardium. Interpretation of the LV myocardium should include evaluation of myocardial hypertrophy, thinning, and/or enhancement. The identification of regional subendocardial or transmural hypoattenuation of the myocardium is suspicious for ischemia or infarction[102] and should warrant further investigation even in the absence of an identifiable critical coronary stenosis. Aortic evaluation is usually possible within the extent of the typical cardiac field of view (generally mid-pulmonary artery to diaphragm). This scan length generally includes the aortic root, most of the ascending aorta and dorsal thoracic aorta, but not the transverse aorta. Within these limitations, the presence of any pathology should be reported. In the case of triple rule-out or coronary bypass full thorax acquisitions, the entire thoracic aorta should be reported. Pulmonary artery pathology should be reported within the constraints of the acquisition protocol. In standard coronary CTA, the contrast administration protocol and the scanned volume used for coronary imaging will be suboptimal for evaluation of the pulmonary vasculature and hence the detection of pulmonary embolism. Nevertheless, large proximal pulmonary emboli may still be detectable as contrast filling defects. Disproportionate enlargement of the right ventricular chamber should raise the suspicion for pulmonary emboli. In patients undergoing triple rule-out procedures, contrast enhancement and field of view should be sufficient to permit review of all pulmonary arterial pathology.

8.2. *Reporting*

Lesion stenosis should be reported semiquantitatively according to the SCCT interpretation and reporting guidelines. The extent of disease should be further qualified by identification of location, extent, and plaque type and location, that is, individually and segmentally, and as calcified, noncalcified, or mixed noncalcified or calcified.[7] Additionally, positive remodeling or other features of lesion complexity should be described.[103–105] Studies have shown that positive remodeling of highly lucent plaques are more common in patients with ACS and that patients with these plaques are more likely to develop ACS in the future. At the present time, there is not sufficient evidence to warrant further immediate evaluation of these plaques before discharge in the absence of coronary stenosis over 50%. Other “complex” features may include ulceration, intraluminal dye penetration, or overhanging edges. These may have prognostic implications, although evidence is not sufficient to provide specific management guidelines based on these findings in patients with nonobstructive CAD.[106–108]

Noncoronary cardiac and noncardiac findings should be included in the body of the report on coronary findings, with particular attention to those that might explain the patient’s presenting symptomatology, for example, aortic dissection, pericardial effusion, pulmonary embolus, and pneumonia.

Scans should be reconstructed immediately after acquisition and the interpreting physicians should be notified immediately to prioritize their analysis. Scan reports should be incorporated as soon as possible into an electronic medical record and abnormal scans must be reported verbally to the referring physician within 60 minutes of the study reconstruction. Ideally, all scan results, including the pertinent noncardiac findings, should be verbally communicated to expedite triage.

8.3. *Management recommendations*

In selected cases, it is appropriate to discuss management recommendations with ED physicians, rather than filing a written report alone without direct discussion, particularly in the presence of abnormal findings. Including management recommendations within the written report is optional and a matter of physician discretion.

ED physicians making critical decisions may not be familiar with the clinical implications of standard coronary CTA grading, particularly when house staff or allied health personnel are communicating results to an attending physician. Management decisions should rely on the evidence from clinical trials, in which the presence of a stenosis greater than 50% was used as a binary cutoff to recommended further evaluation with functional or invasive testing before discharge. However, the additional features previously mentioned regarding the location and extent of disease, plaque type, and complex characteristics suggesting plaque instability may also be considered and discussed directly with ED physicians. Ultimately, the decision to admit or discharge the patient will depend not only on the scan findings but on the clinical presentation, biomarkers, and ECG results, and thus, rests in the hands of attending physicians.

In discussing the clinical implications of coronary CTA findings with referring physicians, it is appropriate to emphasize the distinction between the anatomic findings and the possible physiologic consequence of those findings, and there is evidence that functional testing has incremental value in appropriately selected patients.[109] Specifically, although the distinction is commonly made between lesions that are "greater than 50%" or not, classical hemodynamic studies show that 70% diameter stenosis or more was required to reduce maximal flow reserve. Recently, there has been substantial additional evidence from studies comparing invasive fractional flow reserve to qualitative and quantitative estimated stenosis severity of both coronary CTA and invasive angiography that the correlation between stenosis grade and flow impairment is not reliable. Given these facts, intermediate grade lesions of 50% to 70% are unpredictable in their functional consequence. Therefore, functional evaluation, generally with stress testing with or without imaging, is advisable and should be considered in many of these patients.

8.4. *Management recommendations with known CAD*

The management recommendations with regard to patients with previously known CAD deserve special consideration. The great strength of coronary CTA relies on its extremely high sensitivity and negative predictive value. This allows the rapid division of patients into the majority, who have little or no disease, and those with plaques that may or may not have functional consequences. The specificity and positive predictive value of CTA are significantly lower, to the point that the randomized ED trials specifically recommended functional testing for patients with intermediate-grade (50%–70% stenosis) lesions. Most patients with previously known CAD will include plaques that fall into this category, unless the coronary CTA findings demonstrate that the original diagnosis was erroneous. Even if a severe lesion (>70%) is present, it may be unclear whether that is a new lesion in a patient with previous CAD or whether this would correspond to a functionally significant stenosis on invasive fractional flow reserve testing. Additionally, patients with stents have reduced accuracy for diagnosis of in-stent stenosis compared with native arteries, and in general have multiple other lesions that are likely to require functional analysis.[60] Thus, previously known CAD is a relative contraindication to coronary CTA in patients with ACP, as it will not demonstrate the functional consequences of the multiple plaques that are likely to be found, and thus may merely be a precursor to further testing. As previously mentioned, clinical judgment in an individual patient may vary, so this is not an absolute contraindication.

9. Future developments: functional coronary CTA

As previously described, anatomic stenoses in the range of 50% to 69% detected by coronary CTA are of uncertain clinical significance and may not be the cause of current symptoms in ACP patients. Further evaluation with functional testing is recommended, which necessarily entails further cost and time. To minimize these factors, there is active research into methods to derive functional information from the coronary CTA examination itself.

Evidence from single-center studies and the CORE-320 multicenter trial suggests that the addition of coronary CTA adenosine-stress perfusion scans improve the diagnostic accuracy of coronary CTA alone in predicting the results of invasive angiography combined with functional testing.[110–114] However, evidence from single-center or multicenter trials is not yet available to establish guidelines for the use of this new modality.

Similarly, the Diagnosis of Ischemia-Causing Stenoses Obtained Via Noninvasive Fractional Flow Reserve (DISCOVER-FLOW), Determination of Fractional Flow Reserve by Anatomic Computed Tomographic AngiOgraphy (DeFACTO) study, and Non-invasive fractional flow reserve derived from coronary computed tomography angiography in suspected coronary artery disease: the NXT multicenter trials showed that "coronary CT fractional flow reserve" derived from computational modeling of anatomic CT information improved the accuracy of coronary CTA alone in predicting invasive fractional flow reserve.[115–117] At the time of this writing, there is insufficient evidence to recommend coronary CT fractional flow reserve for clinical use.

From the Evaluation and Triage of Patients With Suspected Acute Cardiac Ischemia (ERASE) trial, it is known that resting

MPI is accurate in detecting patients with ACS.[30] Similarly, CTA studies demonstrate that resting perfusion and LV function assessment improve accuracy of coronary CTA to exclude ACS, especially in patients with indeterminate or nondiagnostic coronary assessment.[117–119] However, these techniques are not yet routinely used, as assessment of LV function is associated with a significant radiation dose penalty except for the most advanced CT technology, where it can be obtained with little additional radiation exposure.

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