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ORIGINAL PAPER

Use of multidetector computed tomography for the assessment of acute chest pain: a consensus statement of the North American Society of Cardiac Imaging and the European Society of Cardiac Radiology

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Preamble

The diagnosis of patients with acute chest pain remains a challenging problem. There are approximately 6 million chest pain related emergency department (ED) visits annually in the US alone [1]. Approximately 5.3% of all ED patients are seen because of chest pain and reported admission rates are between 30% and 72% for these patients [2].

Only 15–25% of patients presenting with acute chest pain are ultimately diagnosed as having an acute coronary syndrome (ACS). Of those patients who were admitted to the chest pain unit, 44% ultimately had

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significant pathology ruled-out in one series [3]. The cost of chest pain triage and management has been estimated to be as high as $8 billion dollars annually with most of those patients ultimately not having ACS [4]. Moreover, 2–8% of patients are discharged from the ED and later diagnosed as having ACS [5–8]. The mortality rate for these patients is approximately 25%, which is twice as high as those who are admitted [7]. Malpractice litigation over missed myocardial infarction (MI) represents the largest proportion of ED lawsuits in the U.S. [9]. There is thus great desire to find new tests to safely and expeditiously discharge low risk patients.

Recent technical advances in cardiovascular CT angiography (CCTA) have shown great promise for improving our diagnostic capabilities through non-invasive imaging. There are several articles showing excellent accuracy for diagnosing coronary heart disease with the latest 64-slice multi-detector CT (MDCT) scanner [10–12]. Newer technology has arrived with dual-source 64-slice MDCT [13] and the imminent introduction of 256-slice MDCT that are expected to further improve on this diagnostic accuracy. Scanners that can perform cardiovascular CT are becoming more widely available. As has been the case for many rapid developments in medicine, in concert with this diffusion of technology there is the risk of application for clinical patient care without the scientific, rigorous study required. The concept of evaluating patients with acute chest pain with ECG-gated CT in the ED is but one such example, where, based on rapidly evolving technology, tests are being pushed to clinical application faster than our ability to scientifically evaluate their benefit. This is in part driven by industry, which wishes to sell more scanners, pioneering entrepreneurs, and by the ED in the setting of acute chest pain, which increasingly relies on imaging to enable faster risk stratification of patients and thereby minimize patient stay and costs. While there is a consensus that CT may indeed improve disposition of patients with acute chest pain, at this point, there is little data demonstrating typical coronary CT findings in patients with and without ACS among patients with chest pain. Thus, there is the potential of inappropriate use of new technology leading to additional testing rather than saving admissions or cost. Data from observational trials are needed to demonstrate the safety and feasibility of CT in the setting of acute chest pain, to identify the target population in whom admissions could be reduced, the relation of CT findings on plaque and stenosis to MI and unstable angina pectoris. Eventually randomized diagnostic trials are essential to prove the incremental value of cardiac CT to current standard of care, including stress testing similar to the evaluation of SPECT a decade ago [14].

Currently there are no guidelines that have been published for the use of CT for acute chest pain. Appropriateness criteria have recently been published [15]. More general guidelines are currently under development. However, because of the great interest and pressure from a variety of groups to utilize this technology, there is value in providing interim guidance. For this reason, the North American Society for Cardiac Imaging (NASCI) and the European Society of Cardiac Radiology (ESCR) assembled a group of expert radiologists, cardiologists and emergency physicians representing the collective experience from the United States, Canada and Europe to review the literature, indicate areas in need for more research

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and provide a basis in the future for the development of comprehensive guidelines.

Co-endorsed White Papers and guidelines by various societies have been written before on various topics. We believe however that this is the first attempt to bring together the different experiences from different countries and continents whose medical systems are significantly different. We believe that this combined experience has the advantage that underlying biases from local practice becomes less relevant and that the underlying fundamental truths become relatively more important. The ESCR and NASCI are planning to work together in the future to bring together experts to discuss available evidence, to provide guidance to the practitioner and to further advance the field of cardiovascular imaging and provide a basis for practice with evolving technologies.

How to manage chest pain: the emergency department perspective

In the emergency department setting, the symptoms and clinical signs of patients with chest pain are variable but it is important to distinguish life threatening causes that need rapid or immediate intervention from those that are less likely to be fatal but still need in-patient treatment and those that can be managed supportively on an out-patient basis (Table 1) [16].

Table 1 Common potential causes of non-traumatic chest pain

Life threatening	Non-life threatening
Acute Coronary Syndrome	Pneumonia/Pulmonary Parenchymal Disease
Pulmonary Embolism	Pulmonary, Mediastinal, or Pleural Neoplasm
Aortic Dissection	Musculoskeletal Injury or Inflammation
Intramural Hematoma	Cholecystitis
Penetrating Aortic Ulcer	Pancreatitis
Aortic Aneurysm/ Rupture	Herpes Zoster
Esophageal Rupture	Hiatus Hernia/GERD/Esophageal Spasm
Pericardial Tamponade	Pericarditis/Myocarditis
Tension Pneumothorax	Simple Pneumothorax

Acute Coronary Syndrome

In the United States more than 335,000 people die of heart disease in an ED or before reaching a hospital every year. Of patients who die suddenly because of coronary heart disease, 50% of men and 64% of women have no previous symptoms. When a patient presents with chest pain, they are typically risk stratified with an appropriate history and physical, and electrocardiogram (ECG), chest X-ray and laboratory studies including cardiac biomarkers. Obtaining a timely ECG is important to identify the small subset of patients with an ST Elevation Myocardial Infarction (STEMI) who will benefit from a coronary intervention (PCI or thrombolysis) The majority of patients without a STEMI are further risk stratified into one of three categories: (1) high risk for acute coronary syndrome (ACS) or Non ST Elevation MI (NSTEMI), (2) low risk for ACS, or (3) noncardiac chest pain. A number of clinical decision rules tools are available to risk stratify patients into one of the above three categories, but none have a high sensitivity and specificity with some no better than clinical impression.

One risk stratification tool that is widely used in emergency departments is the Thrombosis in Myocardial Infarction (TIMI) risk score that predicts the triple endpoint of death, new or recurrent myocardial infarction, or need for urgent target vessel revascularization within 2 weeks of presentation (Table 2) [17].

Table 2 TIMI risk score for Unstable Angina and NSTEMI

- Age ≥65 years
- History of known CAD (documented prior coronary artery stenosis >50%)
- ≥3 conventional cardiac risk factors (age, male sex, family history, hyperlipidemia, diabetes mellitus, smoking, obesity)
- Use of aspirin in the past 7 days
- ST-segment deviation (persistent depression or transient elevation)
- Increased cardiac biomarkers (troponins)
- ≥2 anginal events in the preceding 24 h

TIMI = Thrombosis in Myocardial Infarction; CAD = coronary artery disease

Score = sum of number of above characteristics

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The low risk group is defined by a score of 0 or 1 and a <5% likelihood of requiring intervention. The high risk group is defined by a score of 6 or 7 and a 40% likelihood of requiring intervention. This approach has been validated in a number of additional trials [18–20].

A computerized system for risk assessment is in use in some emergency departments to aid in diagnosis [21]. A risk score for patients with normal troponin concentrations has recently been proposed [22, 23]. Specific recommendations for an early invasive strategy in patients with NSTEMI include any of the following high-risk indicators: [24]

- Recurrent angina/ischemia at rest or with low-level activities despite intensive anti-ischemic therapy.
- Elevated cardiac specific biomarkers, TnT or Tnl.
- New or presumably new ST-segment depression.
- Recurrent angina/ischemia with congestive heart failure symptoms, an S_3 gallop, pulmonary edema, worsening râles, new or worsening mitral valve regurgitation.
- High-risk findings on noninvasive stress testing.
- Depressed left ventricular systolic function (e.g., ejection fraction <40% on noninvasive study).
- Hemodynamic instability
- Sustained ventricular tachycardia.
- Percutaneous Coronary Intervention (PCI) within 6 months.
- Prior CABG.

Treatment and disposition is based on the level of risk assigned to the patient. Patients with a NSTEMI or who are deemed at high risk for ACS are typically admitted to the hospital. Patients with non-cardiac and non-life threatening chest pain are typically discharged home with outpatient follow-up. Low risk ACS patients usually present a quandary. These patients usually require a period of observation with serial enzymes and then a determination is made whether provocative stress testing is required. In some facilities, observation units tailored toward the evaluation of chest pain have made prolonged evaluations in the emergency department possible. Patients receive serial biomarkers, observation in a telemetry setting, and most receive some form of cardiac stress testing. Cardiac stress testing ranges from simple treadmill tests to the newer cardiac PET scans. None of these tests is perfect and most if not all are not available 24 h day/7 days a week. If the patient has rising cardiac biomarkers or has a positive cardiac stress test, they are usually admitted for cardiac catheterization and further management.

In spite of this aggressive approach to chest pain in the ED, even in the population at low risk for ACS, between 2–8% of patients are inappropriately discharged and later found to have an ACS [5–8]. These discharged patients have a significantly increased morbidity and mortality. If it were possible to accurately predict high risk in patients with potential NSTEMI or, conversely, to accurately exclude ACS during the early observation period, the number of patients admitted for evaluation of chest pain could be significantly reduced with a commensurate reduction in cost of care. In addition, the earlier identification of high risk ACS patients could lead to earlier treatment initiated in the Emergency Department with the possibility of improved patient outcomes.

CCTA may be used in order to visualize the coronary arteries and to determine whether there are plaques or thrombi narrowing or occluding the vessel. If CCTA could be performed immediately or during the observation period for ACS at a cost that is less than that required for outpatient monitoring, there would be a significant saving to the health care system. Because of medical malpractice issues in the U.S. [25] and the high likelihood of a poor outcome if a patient with ACS is discharged, the test must have a high negative predictive value minimizing missed ACS. Ideally, the true positives would all undergo coronary artery revascularization and the number of indeterminate cases that require further observation would be reduced. A model Cardiac Chest Pain Pathway that incorporates CCTA is shown in Fig. 1. Early supporting data for the use of CCTA for acute chest pain is now appearing in the literature [26–28].

Although this Pathway represents one possible concept, further work is necessary to clarify the role of stenosis and plaque assessment for risk assessment of patients with acute chest pain. This relates both to the concept of mild to moderate stenosis as detected by CCTA and the necessity of stress testing or coronary angiography (CAG) in these patients, as well as the concept of plaque burden in CCTA as a tool for risk stratification. Both concepts have been recently addressed [26].

Very important for the success of cardiac CT in this application will be our ability to exactly determine

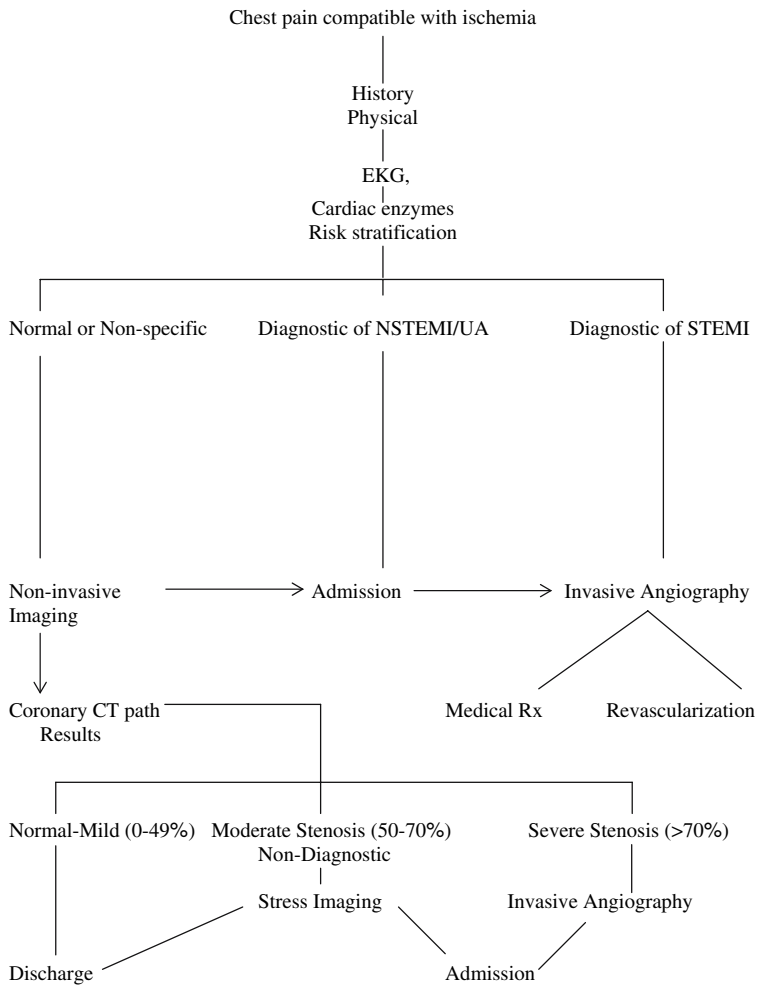

Fig. 1 Model Cardiac Chest Pain Pathway that incorporates CCTA

the target patient population. While the broader population of all comers with undifferentiated chest pain has a very low incidence of ACS, pulmonary embolism (PE), or aortic dissection, patients with inconclusive initial ED evaluation admitted to the hospital to rule out MI may benefit the most as 10–15% of those patients will develop an ACS. Besides the detection of stenosis and plaque it may prove useful to evaluate the additional benefit from the assessment of global and regional LV function, which may identify stunned myocardium.

Pulmonary Embolism

Patients who present to the ED with a suspected PE can be risk stratified using the Wells' clinical decision rule (Table 3). The likelihood of a PE is low if the score is four or less and the D-dimer is

Table 3 Well's Clinical Decision Rule for Pulmonary Embolism [29]

Variable	Points
• Clinical signs and symptoms of deep vein thrombosis	3.0
• Alternative diagnosis less likely than pulmonary embolism	3.0
• Heart rate >100/min	1.5
• Immobilization (>3days) or surgery in the previous 4 weeks	1.5
• Previous pulmonary embolism or deep vein thrombosis	1.5
• Hemoptysis	1.0
• Malignancy (receiving treatment, treated in the last 6 mo or palliative)	1.0

Clinical probability of pulmonary embolism unlikely: 4 or less points; clinical probability of pulmonary embolism likely: more than 4 points

negative. If the patient has a score greater than 4 then further investigations are required to exclude the diagnosis of PE. The most commonly used imaging techniques are a nuclear ventilation/perfusion scan or chest CT depending on institution and availability. A negative CT study is associated with a low risk for subsequent fatal and nonfatal venous thromboembolism (VTE) [28]. Therefore, in the patient with undifferentiated chest pain and a moderate to high probability of PE, a CT is indicated. If the patient is high risk for PE but has a negative CT scan, further testing may be indicated. A normal D-dimer or a negative evaluation of the lower extremity venous system with a contrast CT or US makes the diagnosis of PE unlikely. When the clinical probability is low, a normal D-dimer test excludes the diagnosis of PE and a CT is typically not performed.

Acute Aortic Syndromes

The clinical presentation of patients with acute aortic syndromes typically present with ripping or tearing chest discomfort that is sudden in onset, severe, substernal and may radiate to arms or back. The most common predisposing factors are hypertension, increasing age and pregnancy, while less common syndromes include Marfan's syndrome and Behçet's disease. The pain may start in the epigastrium or abdomen and radiate to the back. Hypotension, unequal pulses, acute aortic regurgitation or suggestive electrocardiographic changes may be features as well. Aortic disease includes entities such as acute aortic dissection, dissecting intramural hematoma, aortic penetrating ulcer, mycotic aneurysm, and atherosclerotic aneurysm with and without rupture. Because these may be fatal, rapid diagnosis and institution of therapy is desirable. MDCT is the diagnostic test most often used to make the diagnosis because it can distinguish among the various etiologies of the acute aortic syndrome and define the extent of the disease process [30].

Alternative diagnoses

MDCT is capable of detecting a multitude of alternative causes of acute chest pain. These include hiatus hernia, pneumonia, intrathoracic mass, pericardial effusion and pericarditis, esophageal mass or rupture, pleural effusion, pancreatitis, spontaneous fracture (spine, sternum, cough fracture of rib). Many patients with ill-defined symptoms or uncharacteristic presentations may be initially considered to have an acute coronary syndrome but may have a pulmonary embolism or another disease. Some patients have more than one disease process causing their symptoms [31].

Triple Rule-Out

MDCT is currently the diagnostic test of choice for the diagnosis of pulmonary embolism and acute aortic syndrome. As mentioned above, alternative diagnoses may also be found or excluded as causes of chest pain. If MDCT were robust enough to exclude an acute coronary syndrome in patients without ST elevation, and sensitive enough to indicate which patients with NSTEMI are likely to have treatable coronary disease, it might be used to shorten the observational period for patients with suspected ACS to either rule-out cardiac causes for chest pain or ensure timely institution of specific therapy. Ultimately, we must ask: Is there a single MDCT study that can be performed that can accurately, expeditiously and cost-effectively diagnose coronary, pulmonary and aortic disease in the ED, the so-called ''triple rule-out?'' The question may also be asked, is there a clinical need for such a test? ED physicians usually feel that it is relatively uncommon that they are uncertain of all three diagnostic considerations, thus, single or dual rule out may be sufficient. As of this writing, there are no large prospective studies where MDCT has been used for this purpose and further research is desirable to better define the role for triple rule-out.

CT protocol

The CT protocol used to evaluate patients who present to the ED is an evolving and multifaceted challenge. The development of newer generations of MDCT that can evaluate the coronary arteries routinely has injected an additional promising but confounding element. As discussed above, the challenge is to distinguish life-threatening cardiac

etiologies such as ACS from non-cardiac causes including pulmonary embolism, and aortic dissection. Specific protocol issues include the appropriate preparation for the CT scan, whether to use calcium scoring, contrast injection parameters, and strategies used to acquire CTA. Ideally, these issues can be addressed in a manner that can be generalized to different types of advanced scanners and practice settings.

Scanner technology

Investigation of the heart and in particular the coronary arteries requires simultaneous fast image acquisition and high spatial resolution. The ability of CT scanners to achieve high temporal and spatial resolution has improved tremendously in recent years. The availability of 64-detector-row CT (64DCT) and, even more recently, Dual Source CT technology, has been of particular value for cardiac CT examinations in that isotropic half-millimeter spatial resolution and temporal resolution as fast as 83 ms is attainable. The spatial resolution of CT is now only 2 to 3 times lower than that of the most optimal conventional coronary angiography (CAG), which is sufficient to visualize small segments of the coronary artery tree down to the third generation vessels [32].

Preparation for the CT scan

In patients with heart rates above 65 bpm, patient preparation with beta-blockers is necessary to achieve sufficiently low heart rates with $\leq$64-slice technology [33]. This typically involves administration of 50–100 mg Metoprolol 1 h prior to the CT scan, followed by 5 to 20 mg Metoprolol intravenously to patients in whom the heart rate is still above 65 bpm once in the CT scanner. In patients in whom the scan must be obtained with a heart rate of 80 bpm and above, image reconstruction in the systolic phase of the cardiac cycle often results in superior image quality [32]. Nitroglycerin (0.5 μg sublingual) is given to dilate the coronary arteries if the patient's blood pressure will tolerate it. With further improvement of technology, beta-blockers may no longer be indicated.

Calcium scoring

Screening for coronary calcium by CT is a fast and simple procedure that allows determination of the amount of calcified plaques in the coronary arteries and estimation of the extent of the entire atherosclerotic plaque burden. Screening for coronary calcium was introduced more than a decade ago with the use of electron beam CT (EBT). Electron beam CT is a dedicated cardiac CT system without moving parts and permits very short exposure times when scanning the heart. The design of this machine made it suitable for low dose cross sectional scanning of the heart to detect coronary calcium.

Coronary calcium screening by EBT is performed with 3 mm consecutive slices through the range of the entire heart. No administration of contrast media is required. Every scan is triggered prospectively by the ECG signal to the mid diastole interval. Usually 40 heartbeats are necessary to acquire the entire volume resulting in a breath-hold time of approximately 30 s. Coronary calcium is identified as lesions in the coronary arteries with a density of 130 HU and above. A score value is calculated by a dedicated algorithm, which takes the peak density and the area of any individual lesion into account [34]. The total score corresponds to the sum of all lesions in all three coronary arteries, and is commonly provided in percentile for age and gender.

Coronary calcium screening may also be performed with MDCT systems. Four slices are minimally required to perform coronary calcium scanning with a MDCT. Depending on the number of slices available, the spiral scan can be performed within 10 to 20 s [35]. To improve reproducibility of the measurement, overlapping slice reconstruction is recommended [36]. However, this results in a relatively high dose of radiation so that a prospectively triggered sequential imaging approach analogous to EBT is commonly used. Images are evaluated according to the procedure suggested for coronary calcium screening with the EBT. To improve the reproducibility and comparability of coronary calcium screening with different CT scanners an international consortium has been founded with the aim to standardize the measurement. The consortium proposed to use the quantification of the absolute mass in mg calcium-hydroxyapartite rather than assessing the calcium score. For the standardized measurement frequent calibration of the CT scanner is required with dedicated phantoms. The foremost issue with coronary calcium screening for patients with acute coronary syndrome is to detect

coronary calcium with a sensitivity that is as high as possible.

Initially, scanning for coronary calcium with EBT was intended to screen for coronary atherosclerosis in asymptomatic persons to determine the risk of acute coronary events. However, in the late nineties some authors reported the use of coronary calcium screening for patients with angina-like symptoms and negative cardiac enzymes. Laudon et al. described the use of CAC scanning in the emergency department in more than 100 patients, pointing out a negative predictive value of 100% [37]. McLaughlin et al. reported a negative predictive value of 98% in 134 patients presenting with chest pain to the emergency department [38]. Georgiou et al. followed almost 200 patients with chest pain in the emergency department and found that the presence of coronary artery calcium in this cohort is a strong predictor for future cardiac events and conversely patients with a negative coronary calcium scan may safely be discharged immediately from the ED [39]. A problem with these studies is that the negative predictive value is not as great in younger patients. Thus coronary calcium may not be widely applicable in this patient population. In addition, because of its high costs and limited availability, EBT has never been widely used as a stand-alone tool to triage patients with chest pain.

Coronary artery calcium scoring by MDCT may be useful in the ED setting prior to CTA in that the quality of the CTA is likely to be impaired or non-diagnostic if large quantities of coronary calcium are found. A decision to proceed with CTA must then be made. Moreover, the calcium score can be compared to existing age and gender benchmarks to guide primary prevention as an outpatient if the patient is not admitted [40, 41]. CAC is relatively common in this patient population even in patients with non-cardiac causes of chest pain. Thus CTA may still be of value to evaluate for stenoses. Clearly, there is a need for more research to define the relative roles of both CAC and CTA for acute chest pain patients. Calcium screening will be addressed in more detail in a future ESCR-NASCI Consensus Statement.

CTA protocol

More advanced MDCT technology allows not only assessment of the calcified atherosclerotic plaque burden but also visualization of the lumen and wall of the coronary arteries using contrast material. In addition, other causes of chest pain such as pulmonary embolism, aortic dissection, and pneumonia can be evaluated using CTA. Provided that optimized images of the entire cardiac cycle are not required, dose modulation or ECG-pulsing can be used to reduce redundant radiation during the systolic phase while preserving coronary artery images of good quality [42]. Specific ED chest pain protocols in which the differential diagnosis includes a coronary artery etiology can be divided into two groups. If the patient is stable and primary clinical suspicion is angina, a dedicated cardiac CTA may be sufficient. Alternatively, if the clinical evaluation is less specific and differential considerations include angina and other serious causes of acute chest pain, a comprehensive or global evaluation may be deemed appropriate. The latter protocol is also termed the triple threat or triple rule-out protocol. Each of these protocols is discussed in turn.

Dedicated CTA

A typical CT angiography (CTA) investigation of the heart with most modern CT scanners usually requires a breath hold time of 10 s or less and 60–80 ml of contrast media. The regimen for intravenous contrast medium administration has changed with newer scanners. Formerly, with slower scanning the priority was to extend the contrast bolus in order to maintain homogenous enhancement during the entire scanning period. Now that the scan time with 64DCT is typically no more than 10 s for the entire heart, high contrast enhancement must be achieved during the comparatively short scanning period. One method is to calculate the amount of contrast medium based on the bodyweight of the patient; for every kilogram of bodyweight administering 0.5 g of iodine. For a cardiac CT study the bodyweight-adapted amount of contrast medium is administered within 20 s. Highly concentrated contrast media is well suited to this approach, in order to keep the intravenous flow rate within a reasonable order of magnitude, particularly in obese patients. To lower the viscosity and to improve administration the contrast medium should be warmed to body temperature. In order to achieve correct timing, either a test injection or automated threshold-based bolus timing may be used. The

threshold with automated bolus timing is often set at 150 HU.

In principle it is advisable to have some contrast in the right ventricle in order to identify the septum and the right ventricular myocardium. However, any CTA study should be performed in mid-inspiration in order to avoid the ''Valsalva maneuver''. This effect occurs during deep inspiration when an influx of contrast medium into the right atrium is impeded resulting in non-homogenous enhancement of the cardiac structures. A saline flush should always be performed immediately after the administration of contrast medium in order to flush the veins of remaining contrast medium and to maintain a tight contrast bolus, while it aids in the assessment of the right coronary artery and posterior descending artery. The scanning range extends from the level of the carina inferiorly to below the cardiac apex.

A number of studies have compared 64DCT and CAG on a segment-by-segment basis for the detection of coronary artery stenoses in the non-emergent setting [11, 12, 43, 44]. Although 10–20% of coronary artery segments cannot be assessed by CTA because of motion artifacts or severe calcifications, the negative predictive value of this technique is close to 100%, rendering CT a reliable method to rule out coronary artery disease if the study can be performed successfully. Unfortunately, the positive predictive value is only around 75%, revealing a tendency of CTA to overestimate the degree of coronary artery stenoses. One of the reasons for overestimation may be the presence of plaques which appear to narrow the lumen, if adjacent widening of the outer lumen (positive remodeling) is not taken into account. Underestimation of the degree of stenosis by CAG due to eccentric stenosis and suboptimal angulation is presumably another cause. The largest cohort reported so far with CCTA in the ED comprised 103 patients with acute chest pain. By using $\geq$50% coronary artery stenosis as detected by MDCT as a threshold with clinical follow-up as the reference standard, Hoffmann et al. reported a positive and negative predictive value of 47% and 100% for ACS, respectively [26].

In a pilot study of 22 patients, Dorgelo et al. reported on the potential use of MDCT to triage patients with ACS among conservative treatment, percutaneous intervention or bypass grafting [45]. They followed a simplified stratification scheme taking the number of coronary vessels into account affected by coronary artery disease with stenosis $\geq$50%. According to this scheme, the absence of coronary artery disease, single- or two-vessel disease, and left main or three-vessel disease initiated conservative, interventional and surgical therapy, respectively. They reported excellent agreement for decisions made by MDCT and CAG for triaging these patients with ACS. Interestingly, in some patients MDCT more often showed the tendency to triage for coronary intervention whereas after cardiac catheterization these few patients were treated conservatively. This presumably resulted from lack of adequate clinical information such as co-morbidity risk at MDCT that was available and influenced the final decision after cardiac catheterization [45].

Global Assessment (Triple Rule-Out)

The protocol for global assessment differs from dedicated coronary CTA in several important respects. First, a large field of view is used to encompass the entire chest. Second, the entire length of thorax must be imaged in order to assess the pulmonary vasculature to a subsegmental level, as well as the thoracic aorta. Such imaging requires a longer acquisition of 15 s or more with 64-DCT with more opportunity for motion artifact due to breathing. It is therefore advisable to begin image acquisition below the cardiac apex and scan superiorly, in contrast to the cephalocaudal direction typically used for dedicated CCTA. This approach permits imaging of the coronary arteries during the first part of the scan, when breath holding is presumably better.

A third important difference is the protocol for contrast administration. Unlike dedicated coronary CTA, where partial or complete washout of contrast in the right heart is desirable, a triple rule-out protocol must provide optimal enhancement of both the right and left heart for simultaneous visualization of the pulmonary arteries, the aorta and the coronary arteries. Thus, a small amount of additional contrast may be necessary and contrast bolus administration may need to be lengthened.

Using the global assessment chest pain protocol, White et al. investigated 69 patients with chest pain in whom they assessed the amount of calcium, the degree of stenosis, ejection fraction, wall motion

abnormalities, and perfusion defects in the myocardium [28]. The final diagnosis was derived from clinical exam or follow up for 1 month. The CT was normal, showed coronary artery disease, non-cardiac related or non-concordant findings in 75, 14, 4, 7% of patients, respectively. For the diagnosis of acute coronary syndrome they reported a sensitivity and specificity of 87 and 96%, respectively. In addition White et al. reported findings in other areas such as the lung, mediastinum and the bones. In this study there were too few patients with aortic dissection or pulmonary embolism to adequately establish the diagnostic accuracy of this protocol for non-coronary causes of acute chest pain.

Imaging evaluation and Post Processing

Within the context of an urgent clinical presentation, the initial assessment of the CT scan must be rapid and accurate for effective risk assessment of the patient. In the broadest sense this means determining if the patient is suffering from a life threatening condition necessitating urgent therapy, such as an acute coronary syndrome, an acute aortic syndrome, or venous thromboembolism. This assessment rarely requires visualization techniques beyond appropriately windowed transverse reconstructions. Although transverse sections represent the most basic output of the CT scanner, attention must be focused on proper assessment, as lesions can be missed or mischaracterized. In particular if the window center is too low or narrow, an intimal flap within the aorta or a pulmonary embolism can disappear within the contrast-enhanced lumen or a coronary occlusion associated with calcific plaque could be mistaken for a patent artery. As a general rule of thumb, proper window width and center settings require that the arterial lumen be not rendered as white, but an intermediate gray level. Moreover, the size of mural calcium will be overestimated (blooming) if it is not rendered with an opacity level below white. As was previously discussed, a thin-section acquisition, preferably with overlapping reconstructions is critical to fully assessing vascular abnormalities. With a thoracic CT angiogram comprising 400–4,000 transverse reconstructions, it is impractical to effectively track the structures of interest across multiple sheets of film and spatial relationships will be difficult to ascertain.

If one of the aforementioned acute vascular abnormalities is excluded based upon transverse section review, then post processing will not be necessary. While this should almost always be the case when diagnosing an acute aortic syndrome or pulmonary embolism, the confident exclusion of an acute coronary syndrome may require a post-processing workstation, particularly if there are motion-related artifacts or calcified plaque.

A post-processing workstation is required if an acute aortic or an acute coronary syndrome is diagnosed or if an acute coronary syndrome cannot be excluded. With an acute aortic syndrome, planning of definitive therapy or triage to a period of monitoring necessitates characterization of the aortic lumen, wall, branches, and adjacent structures. A detailed description of the full scope of evaluations necessary to fully characterize an acute aortic syndrome is beyond the scope of this manuscript, but the use of multiplanar reformations (MPRs), curved planar reformations (CPRs), maximum intensity projections (MIP), and volume renderings are key to enabling complete characterization and documentation of the abnormality to facilitate communication with the treating physicians. Moreover, a post-processing workstation is necessary to measure important distances along axes and curved paths that are aligned with aortic landmarks and not the CT table, as is the case with the primary transverse reconstructions.

When characterizing or excluding acute coronary syndromes or acute aortic syndromes assessed with ECG gated CT acquisitions, the post-processing workstation must also be capable of managing multiphasic or four-dimensional data to allow seamless volumetric exploration and analysis across the temporal phases. While the tools of MPR, CPR, MIP and volume rendering frequently are all necessary for a complete assessment, the workstation must be capable of managing up to 3–4,000 images simultaneously to allow seamless exploration of the 4-D data. In the case of an acute coronary syndrome, the primary goal of the analysis should be the identification of the location and extent of the coronary artery occlusion. While, as mentioned above, primary transverse section review can allow exclusion of the diagnosis, full characterization of the extent of the abnormality, particularly in association with chronic atherosclerotic coronary occlusive disease, requires

MPRs oriented perpendicular to median axis of the artery and/or CPRs. Volume rendering can provide an exquisite display of the relationships of the coronary arteries relative to the myocardium, but this is rarely necessary for urgent risk assessment.

When all phases are reconstructed across the cardiac cycle, then MPRs oriented along the standard cardiac axes can be viewed to assess for wall motion abnormalities and perfusion deficits.

Physician requirements

In the United States there are competency guidelines that provide minimum training requirements for radiologists, cardiologists, and nuclear medicine physicians for the interpretation of CTA [46, 47]. In both Europe and Canada, government regulations largely limit interpretation to radiologists. Like all of imaging, there is a learning curve and some training is desirable in order to achieve a measure of competence. The extra-cardiac portion of the examination must be thoroughly evaluated as it has been shown that there may be significant non-cardiac abnormalities in the population of interest [48, 49]. Generally, this will require a radiologist over-read if the radiologist is not the primary reader. The American College of Radiology cautions against the practice of split-reads, and legal consultation is advisable in the U.S. [50].

Future directions

Ongoing research in CT technology suggests that the evaluation of coronary arteries with MDCT will improve substantially in the coming years. Software improvements in post-processing will permit rapid reconstruction of the coronary arteries with automated selection of the optimal cardiac phase. Hardware improvements include better *z*-axis coverage generating a larger number of slices as well as better temporal resolution through the use of multiple tube technology or faster gantry rotation. Such advances in technology can be expected to improve the quality of coronary artery imaging, particularly for the large coverage required for the global assessment and will undoubtedly stimulate further modifications in the CT imaging protocols for ED patients with chest pain.

Summary

The major diagnostic concerns for acute chest pain are acute myocardial infarction and acute coronary syndrome. However, since enzyme blood levels may be normal for many hours following an event, and because ECG findings are often non-diagnostic, 2.8 million patients with acute chest pain in the U.S. are admitted to hospital for evaluation and management of chest pain. This patient subgroup has a low risk for ACS yet undergo expensive investigations since the likelihood of bad outcome is extremely high with a missed diagnosis.

In patients with chest pain whose history, clinical findings and/or predisposing conditions suggest other life threatening diseases, specifically acute aortic syndromes or pulmonary embolism, MDCT is proven to be the diagnostic study of choice [51, 52]. The CT protocol used should be optimized to evaluate each of these specific diagnoses, as completely as possible; this implies that no single protocol is ideal for all chest pain disease.

Regarding myocardial ischemia, numerous studies have established that 16 and 64 slice MDCT has high diagnostic accuracy for detecting significant coronary artery stenosis in stable patients with a high prevalence of coronary artery disease. Furthermore, preliminary studies indicate that MDCT can also detect and characterize atherosclerotic plaque, and these findings are in good agreement with intravascular ultrasound (IVUS). It is therefore tempting to believe that MDCT could identify patients with chest pain of uncertain cause in the ED, many of whom could then be safely discharged. Published pilot studies in which MDCT was used to evaluate patients in the ED for this purpose look promising, but have only involved small patient numbers, and cannot be regarded as definitive [26–28]. The Writing Group feels that MDCT may provide novel and accurate information on the presence of CAD, and can also evaluate aortic dissection and pulmonary embolism. However, large blinded clinical trials are needed to determine the accuracy and precision of MDCT for triage of patients with acute chest pain. Randomized trials should be performed to evaluate the degree to which MDCT enhances patient risk stratification, the consequences of a universally standardized as opposed to a targeted protocol, patient outcomes, and cost-effectiveness compared with the current

standard of care. Staffing issues also need to be addressed since sufficient numbers of CT trained physicians and technologists will be needed; ideally, facilities should offer ECG gated MDCT service 24 h/day and 7 days per week.

Finally, the Writing Group was unanimous in its belief that minimally invasive MDCT has indeed considerable potential for improving the management of selected patients with acute chest pain, and that the necessary clinical research trials to clarify and establish its role in the ED should proceed with urgency.

References

1. Selker HP, Zalenski RJ, Antman EM et al (1997) An evaluation of technologies for identifying acute cardiac ischemia in the emergency department: a report from a National Heart Attack Alert Program Working Group. Ann Emerg Med 29(1):13–87
2. Graff LG, Dallara J, Ross MA et al (1997) Impact on the care of the emergency department chest pain patient from the chest pain evaluation registry (CHEPER) study. Am J Cardiol 80(5):563–568
3. Pozen MW, D'Agostino RB, Selker HP, Sytkowski PA, Hood WB Jr. (1984) A predictive instrument to improve coronary-care-unit admission practices in acute ischemic heart disease. A prospective multicenter clinical trial. N Engl J Med 310(20):1273–1278
4. Fineberg HV, Scadden D, Goldman L (1984) Care of patients with a low probability of acute myocardial infarction. Cost effectiveness of alternatives to coronary-care-unit admission. N Engl J Med 310(20):1301–1307
5. Goldman L, Cook EF, Johnson PA, Brand DA, Rouan GW, Lee TH (1996) Prediction of the need for intensive care in patients who come to the emergency departments with acute chest pain. N Engl J Med 334(23):1498–1504
6. Lee TH, Goldman L (2000) Evaluation of the patient with acute chest pain. N Engl J Med 342(16):1187–1195
7. Lee TH, Rouan GW, Weisberg MC et al (1987) Clinical characteristics and natural history of patients with acute myocardial infarction sent home from the emergency room. Am J Cardiol 60(4):219–224
8. Pope JH, Aufderheide TP, Ruthazer R et al (2000) Missed diagnoses of acute cardiac ischemia in the emergency department. N Engl J Med 342(16):1163–1170
9. Rusnak RA, Stair TO, Hansen K, Fastow JS (1989) Litigation against the emergency physician: common features in cases of missed myocardial infarction. Ann Emerg Med 18(10):1029–1034
10. Leber AW, Knez A, von Ziegler F et al (2005) Quantification of obstructive and nonobstructive coronary lesions by 64-slice computed tomography: a comparative study with quantitative coronary angiography and intravascular ultrasound. J Am Coll Cardiol 46(1):147–154
11. Pugliese F, Mollet NR, Runza G et al (2006) Diagnostic accuracy of non-invasive 64-slice CT coronary angiography in patients with stable angina pectoris. Eur Radiol 16(3):575–582
12. Raff GL, Gallagher MJ, O'Neill WW, Goldstein JA (2005) Diagnostic accuracy of noninvasive coronary angiography using 64-slice spiral computed tomography. J Am Coll Cardiol 46(3):552–557
13. Scheffel H, Alkadhi H, Plass A et al (2006) Accuracy of dual-source CT coronary angiography: First experience in a high pre-test probability population without heart rate control. Eur Radiol 16(12):2739–2747
14. Udelson JE, Beshansky JR, Ballin DS et al (2002) Myocardial perfusion imaging for evaluation and triage of patients with suspected acute cardiac ischemia: a randomized controlled trial. Jama 288(21):2693–2700
15. Hendel RC, Patel MR, Kramer CM et al (2006) ACCF/ACR/SCCT/SCMR/ASNC/NASCI/SCAI/SIR 2006 appropriateness criteria for cardiac computed tomography and cardiac magnetic resonance imaging: a report of the American College of Cardiology Foundation Quality Strategic Directions Committee Appropriateness Criteria Working Group, American College of Radiology, Society of Cardiovascular Computed Tomography, Society for Cardiovascular Magnetic Resonance, American Society of Nuclear Cardiology, North American Society for Cardiac Imaging, Society for Cardiovascular Angiography and Interventions, and Society of Interventional Radiology. J Am Coll Cardiol 48(7):1475–1497
16. Jeudy J, Waite S, White CS (2006) Nontraumatic thoracic emergencies. Radiol Clin North Am 44(2):273–293, ix
17. Antman EM, Cohen M, Bernink PJ et al (2000) The TIMI risk score for unstable angina/non-ST elevation MI: A method for prognostication and therapeutic decision making. Jama 284(7):835–842
18. Cohen M, Demers C, Gurfinkel EP et al (1998) Low-molecular-weight heparins in non-ST-segment elevation ischemia: the ESSENCE trial. Efficacy and Safety of Subcutaneous Enoxaparin versus intravenous unfractionated heparin, in non-Q-wave Coronary Events. Am J Cardiol 82(5B):19L–24L
19. Manoharan G, Adgey AA (2002) Current management of unstable angina: lessons from the TACTICS-TIMI 18 trial. Am J Cardiovasc Drugs 2(4):237–243
20. Mega JL, Morrow DA, Sabatine MS et al (2005) Correlation between the TIMI risk score and high-risk angiographic findings in non-ST-elevation acute coronary syndromes: observations from the Platelet Receptor Inhibition in Ischemic Syndrome Management in Patients Limited by Unstable Signs and Symptoms (PRISM-PLUS) trial. Am Heart J 149(5):846–850
21. Selker HP, Beshansky JR, Griffith JL et al (1998) Use of the acute cardiac ischemia time-insensitive predictive instrument (ACI-TIPI) to assist with triage of patients with chest pain or other symptoms suggestive of acute cardiac ischemia. A multicenter, controlled clinical trial. Ann Intern Med 129(11):845–855
22. Sanchis J, Bodi V, Llacer A et al (2005) Risk stratification of patients with acute chest pain and normal troponin concentrations. Heart 91(8):1013–1018
23. Sanchis J, Bodi V, Nunez J et al (2005) New risk score for patients with acute chest pain, non-ST-segment deviation,

and normal troponin concentrations: a comparison with the TIMI risk score. J Am Coll Cardiol 46(3):443–449
24. Braunwald E, Antman EM, Beasley JW et al (2002) ACC/AHA 2002 guideline update for the management of patients with unstable angina and non-ST-segment elevation myocardial infarction–summary article: a report of the American College of Cardiology/American Heart Association task force on practice guidelines (Committee on the Management of Patients With Unstable Angina). J Am Coll Cardiol 40(7):1366–1374
25. Katz DA, Williams GC, Brown RL et al (2005) Emergency physicians' fear of malpractice in evaluating patients with possible acute cardiac ischemia. Ann Emerg Med 46(6):525–533
26. Hoffmann U, Nagurney JT, Moselewski F et al (2006) Coronary multidetector computed tomography in the assessment of patients with acute chest pain. Circulation 114(21):2251–2260
27. Hoffmann U, Pena AJ, Moselewski F et al (2006) MDCT in early triage of patients with acute chest pain. AJR Am J Roentgenol 187(5):1240–1247
28. White CS, Kuo D, Kelemen M et al (2005) Chest pain evaluation in the emergency department: can MDCT provide a comprehensive evaluation? AJR Am J Roentgenol 185(2):533–540
29. Wells PS, Anderson DR, Rodger M et al (2000) Derivation of a simple clinical model to categorize patients probability of pulmonary embolism: increasing the models utility with the SimpliRED D-dimer. Thromb Haemost 83(3):416–420
30. Khan IA, Nair CK (2002) Clinical, diagnostic, and management perspectives of aortic dissection. Chest 122(1):311–328
31. Thoongsuwan N, Stern EJ (2002) Chest CT scanning for clinical suspected thoracic aortic dissection: beware the alternate diagnosis. Emerg Radiol 9(5):257–261
32. Wintersperger BJ, Nikolaou K, von Ziegler F et al (2006) Image quality, motion artifacts, and reconstruction timing of 64-slice coronary computed tomography angiography with 0.33-s rotation speed. Invest Radiol 41(5):436–442
33. Pannu HK, Alvarez W Jr., Fishman EK (2006) Beta-blockers for cardiac CT: a primer for the radiologist. AJR Am J Roentgenol 186(6 Suppl 2):S341–S345
34. Agatston AS, Janowitz WR, Hildner FJ, Zusmer NR, Viamonte M Jr, Detrano R (1990) Quantification of coronary artery calcium using ultrafast computed tomography. J Am Coll Cardiol 15(4):827–832
35. Becker CR, Kleffel T, Crispin A et al (2001) Coronary artery calcium measurement: agreement of multirow detector and electron beam CT. AJR Am J Roentgenol 176(5):1295–1298
36. Ohnesorge B, Flohr T, Fischbach R et al (2002) Reproducibility of coronary calcium quantification in repeat examinations with retrospectively ECG-gated multisection spiral CT. Eur Radiol 12(6):1532–1540
37. Laudon DA, Vukov LF, Breen JF, Rumberger JA, Wollan PC, Sheedy PF II (1999) Use of electron-beam computed tomography in the evaluation of chest pain patients in the emergency department. Ann Emerg Med 33(1):15–21
38. McLaughlin VV, Balogh T, Rich S (1999) Utility of electron beam computed tomography to stratify patients presenting to the emergency room with chest pain. Am J Cardiol 84(3):327–328, A328
39. Georgiou D, Budoff MJ, Kaufer E, Kennedy JM, Lu B, Brundage BH (2001) Screening patients with chest pain in the emergency department using electron beam tomography: a follow-up study. J Am Coll Cardiol 38(1):105–110
40. Hoff JA, Chomka EV, Krainik AJ, Daviglus M, Rich S, Kondos GT (2001) Age and gender distributions of coronary artery calcium detected by electron beam tomography in 35,246 adults. Am J Cardiol 87(12):1335–1339
41. Naghavi M, Falk E, Hecht HS et al (2006) From vulnerable plaque to vulnerable patient–Part III: executive summary of the Screening for Heart Attack Prevention and Education (SHAPE) Task Force report. Am J Cardiol 98(2A):2H–15H
42. Poll LW, Cohnen M, Brachten S, Ewen K, Modder U (2002) Dose reduction in multi-slice CT of the heart by use of ECG-controlled tube current modulation (''ECG pulsing''): phantom measurements. Rofo 174(12):1500–1505
43. Leschka S, Alkadhi H, Plass A et al (2005) Accuracy of MSCT coronary angiography with 64-slice technology: first experience. Eur Heart J 26(15):1482–1487
44. Mollet NR, Cademartiri F, van Mieghem CA et al (2005) High-resolution spiral computed tomography coronary angiography in patients referred for diagnostic conventional coronary angiography. Circulation 112(15):2318–2323
45. Dorgelo J, Willems TP, Geluk CA, van Ooijen PM, Zijlstra F, Oudkerk M (2005) Multidetector computed tomography-guided treatment strategy in patients with non-ST elevation acute coronary syndromes: a pilot study. Eur Radiol 15(4):708–713
46. Budoff MJ, Cohen MC, Garcia MJ et al (2005) ACCF/AHA clinical competence statement on cardiac imaging with computed tomography and magnetic resonance: a report of the American College of Cardiology Foundation/American Heart Association/American College of Physicians Task Force on Clinical Competence and Training. J Am Coll Cardiol 46(2):383–402
47. Jacobs JE, Boxt LM, Desjardins B, Fishman EK, Larson PA, Schoepf UJ (2006) ACR Practice Guideline for the Performance and Interpretation of Cardiac Computed Tomography (CT). J Am Coll Radiol 3:677–685
48. Onuma Y, Tanabe K, Nakazawa G et al (2006) Noncardiac findings in cardiac imaging with multidetector computed tomography. J Am Coll Cardiol 1848(2):402–406
49. Rumberger JA (2006) Noncardiac abnormalities in diagnostic cardiac computed tomography: within normal limits or we never looked! J Am Coll Cardiol 48(2):407–408
50. ACR White Paper on Split Interpretations. American College of Radiology, Reston, VA. (2006) Available from: http://www.acr.org/s_acr/doc.asp?CID=2600&DID=24277
51. Hayter RG, Rhea JT, Small A, Tafazoli FS, Novelline RA (2006) Suspected aortic dissection and other aortic disorders: multi-detector row CT in 373 cases in the emergency setting. Radiology 238(3):841–852
52. Stein PD, Fowler SE, Goodman LR et al (2006) Multidetector computed tomography for acute pulmonary embolism. N Engl J Med 354(22):2317–2327