ECG-Gated 64-MDCT Angiography in the Differential Diagnosis of Acute Chest Pain

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OBJECTIVE. The most important differential diagnoses of acute chest pain include myocardial infarction, aortic dissection, and pulmonary embolism. The purpose of this study was to evaluate the diagnostic value of an ECG-gated 64-MDCT angiography protocol for simultaneous assessment of the pulmonary arteries, coronary arteries, and aorta within a single breath-hold.

SUBJECTS AND METHODS. In 55 patients with acute chest pain, ECG-gated CT angiography was performed with a CT system in which 64 slices per gantry rotation were acquired. Density measurement and visual assessment of motion artifacts were performed to evaluate image quality. CT findings were correlated with results of laboratory tests and clinical follow-up. For 20 patients, two independent blinded reviewers compared findings on CT angiography with those on X-ray coronary angiography.

RESULTS. Adequate contrast enhancement of the pulmonary vessels, coronary arteries, and aorta was achieved in all cases. Regarding image quality of the coronary arteries, there was minor blurring in seven patients, and in one examination the images did not provide enough information for diagnosis. The average image quality rating was 1.2 on a scale in which 1 indicated no artifacts; 2, minor motion artifacts; and 3, image insufficient for diagnosis. The cause of chest pain was correctly identified with MDCT in 37 patients. The diagnoses included pulmonary embolism (n = 10), coronary stenosis (n = 9), and aortic dissection (n = 1). In four patients, additional diagnoses were found with other examinations.

CONCLUSION. With current techniques, ECG-gated CT angiography of the entire chest has very good image quality. The protocol proved helpful in the differential diagnosis of acute chest pain.

Studies have shown that as many as 7% of visits to emergency departments involve complaints related to chest pain [1]. The preamble of the “Clinical Policy for the Initial Approach to Adults Presenting with a Chief Complaint of Chest Pain, with No History of Trauma” of the American College of Emergency Physicians [1] states, “Myocardial infarction, pulmonary embolus, and aortic dissection are diseases associated with sudden death” and “these diseases may be difficult to diagnose in the emergency department.” The Task Force on the Management of Chest Pain of the European Society of Cardiology [2] reported that “most studies evaluating symptom severity in relation to outcome have focused on patients having either a suspected acute coronary syndrome or suspected acute myocardial infarction” and “one has to keep in mind that other diagnoses, including aortic dissection, pulmonary embolism and pneumothorax” also necessitate immediate intervention.

These guidelines and the American College of Radiology Appropriateness Criteria on Acute Chest Pain [3] call for use of ECG and serum cardiac markers as first diagnostic measures and, depending on the patient’s history, chest radiography, ventilation–perfusion scanning, resting myocardial perfusion scanning, echocardiography, CT, and aortic imaging or pulmonary angiography as further diagnostic steps. However, the initial symptoms of individual patients often are not characteristic [4, 5], and the various examinations needed for diagnosis can be time consuming and expensive. Therefore the initial focus should be on the possibility of the presence of acute life-threatening conditions, including acute ischemic heart disease, aortic dissection, and pulmonary embolism [6].

Although MDCT angiography is widely accepted and routinely used as a primary tool in
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Imaging Technique

The patients were examined with an MDCT scanner (Somatom Sensation 64, Siemens Medical Solutions) in which 64 slices per gantry rotation were acquired at a gantry rotation time of 330 milliseconds. First, a coronal topogram was acquired to determine scan volume, which included the entire chest. A dual-head power injector (Stellant D, Medrad) was used for injection of contrast medium. Iopromide (Ultrast 300, Schering) was used as the contrast agent in all cases. To adapt the volume of contrast medium to the individual scan range for various scan times (21.4 ± 3.2 seconds), volume was adapted to scan length according to Table 1, in accordance with previous experience. Mean contrast volume was 136.9 ± 17.6 mL. Flow rate also was adjusted to scan length (Table 1) for a mean of 4.6 ± 0.5 mL/s. A saline chaser bolus of 50 mL was injected at the same flow rate. An antecubital vein was used for IV access in 47 patients. Seven patients had central venous lines, which were used for injection.

A bolus-tracking technique (CARE bolus, Siemens) in the ascending aorta was used for timing. After a delay of 4 seconds, axial images at the level of the ascending aorta were acquired with an interval of 2 seconds between subsequent images. As soon as a density of more than 100 H was detected in the region of interest in the ascending aorta, the scan was initiated with a delay of 6 seconds.

For scanning in the craniocaudal direction, collimation of 32 × 0.6 mm was used at a gantry rotation time of 0.33 seconds. Double z sampling resulted in 64 reconstructed slices per gantry rotation and an increased spatial resolution of 0.4 mm. Tube voltage was 120 kV; effective tube current, 750 mAs; and table feed, 11.6 mm/s, corresponding to a pitch of 0.2. For four obese patients, tube current was increased to 850–900 mAs. Total scanning time was 21.4 ± 3.2 seconds for the entire chest, depending on volume covered. ECG was recorded during acquisition.

Image Reconstruction

Depending on the patient’s heart rate, retrospective ECG gating with single half-segment reconstruction or, for heart rates greater than 75 beats/min, two-segment reconstruction (Adaptive Cardiac Volume, Siemens) was used. For optimal, motion-free image quality of the coronary arteries, data sets were preferentially reconstructed in mid-diastole. A stack of axial images containing the volume of the heart and the aortic root was reconstructed with a slice thickness of 0.75 mm and an increment of 0.5 mm. In addition, axial images of the entire chest were reconstructed with a slice thickness and an increment of 3 mm. Additional coronal reconstructions and volume-rendered images were available to the radiologist on request.

TABLE 1: Contrast Medium Injection Regimen

<table>
<thead>
<tr>
<th>Scan Duration (s)</th>
<th>Volume (mL)</th>
<th>Flow (mL/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>120</td>
<td>4.5</td>
</tr>
<tr>
<td>16</td>
<td>130</td>
<td>4.5</td>
</tr>
<tr>
<td>18</td>
<td>140</td>
<td>4.5</td>
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<tr>
<td>20</td>
<td>140</td>
<td>4.5</td>
</tr>
<tr>
<td>22</td>
<td>150</td>
<td>4.0</td>
</tr>
<tr>
<td>24</td>
<td>160</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Image Analysis

The images were interpreted on a PACS workstation by a resident and an attending physician or fellow immediately after the examination and later interpreted by a third reviewer on a 3D workstation (Leonardo, Siemens) for final diagnosis, image quality, and density measurements. The following three-point grading system was used for evaluation of pulsation artifacts: 1, depiction of the coronary arteries without motion artifacts; 2, minor motion artifacts but sufficient depiction of coronary arteries for diagnostic purposes; 3, insufficient image quality for diagnostic assessment.

In 20 cases, X-ray coronary angiograms were available for correlation. Ten patients had undergone coronary angiography within 1 year before CTA. The other 10 patients underwent coronary angiography within 4 days after CTA for confirmation of or intervention in lesions detected with CTA. The interpreting radiologists were unaware of the results of previous X-ray coronary angiography. Both reviewers assessed the CTA images of the coronary arteries and indicated potentially hemodynamically significant (i.e., occlusion or stenosis > 50%) and insignificant lesions in the individual segments according to the American Heart Association 15-segment model [12]. The results of consensus interpretation were compared with the findings on conventional coronary angiography.

Clinical Follow-Up

For follow-up until August 2005 (i.e., a period of at least 5 months), the files of all patients were reviewed with a focus on additional diagnoses and on creatinine levels to detect contrast-induced nephropathy. Cardiac enzyme levels were reviewed for detection of hemodynamically significant stenosis or occlusion of the coronary arteries.

Statistical Analysis

Continuous variables were presented as mean ± SD. The diagnostic accuracy of CTA in the detection of coronary artery stenosis was evaluated with quantitative X-ray coronary angiography as the...
standard of reference. Sensitivity, specificity, negative predictive value, and positive predictive value were calculated. Interobserver agreement for the two reviewers was quantified with kappa value (MedCalc software version 7.0.0.1, 2002). Kappa values were interpreted as follows: < 0.20, poor agreement; 0.21–0.40, fair agreement; 0.41–0.60, moderate agreement; 0.61–0.80, good agreement; and 0.81–1.00, very good agreement. For all statistical tests, \( p < 0.05 \) was considered statistically significant.

### Results

#### Technical Issues

CTA was performed successfully and without complications in all patients. The mean cranio-caudal scan range was 248 ± 36 mm; scan duration was 21.4 ± 3.2 seconds. One patient was not able to hold his breath for the scan duration, causing minor artifacts in the caudal section of the scan volume. Opacification of the pulmonary arteries and veins, coronary arteries, and aorta was sufficient in all patients (Figs. 1A and 1B). The measured density values are given in Table 2. At heart rates less than 70 beats/min, reconstruction delay was 65% ± 8%, representing diastolic reconstruction. The delay was 46% ± 15% for higher heart rates, corresponding to predominantly systolic reconstruction. Thus average reconstruction delay was 55% ± 15% of the R-R interval, or 509 ± 202 milliseconds after the R peak of the ECG.

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**Fig. 1**—66-year-old woman with acute chest pain. 
A, Volume-rendered image of chest shows pulmonary vessels, coronary arteries, and aorta. 
B, Volume-rendered image shows adequate contrast enhancement of coronary vessels. 
C, CT scan shows segmental pulmonary embolism (arrow).
Patient Findings

In 37 patients, the cause of chest pain was identified in the CT examination. Table 3 shows a list of diagnoses found. In 14 patients, CTA findings did not explain the chest pain adequately and were in accordance with the clinical follow-up findings, which also did not reveal a diagnosis. In four patients, follow-up findings revealed causes of chest pain that had not been identified on CTA. In one patient, pulmonary congestion was evident on the CT scan. The diagnosis was high-grade insufficiency of the mitral valve, and the patient underwent valve replacement. Another patient had intermittent arrhythmia and received a pacemaker. The condition of another patient was diagnosed as endocarditis. In one patient chest pain was caused by stenosis of the circumflex branch of the left coronary artery, as proved with conventional X-ray coronary angiography, and the stenosis was dilated and stented. CTA depicted this lesion, but the degree of stenosis was underestimated.

TABLE 2: Measured Density Values

<table>
<thead>
<tr>
<th>Structure or Vessel</th>
<th>Density (H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left ventricle</td>
<td>317 ± 57</td>
</tr>
<tr>
<td>Right ventricle</td>
<td>314 ± 99</td>
</tr>
<tr>
<td>Ascending aorta</td>
<td>325 ± 56</td>
</tr>
<tr>
<td>Aortic arch</td>
<td>295 ± 60</td>
</tr>
<tr>
<td>Pulmonary artery</td>
<td>345 ± 79</td>
</tr>
<tr>
<td>Proximal right coronary artery</td>
<td>320 ± 62</td>
</tr>
<tr>
<td>Left main coronary artery</td>
<td>327 ± 72</td>
</tr>
</tbody>
</table>

TABLE 3: Imaging Findings in Study Population

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>No. of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulmonary embolism</td>
<td>10</td>
</tr>
<tr>
<td>High-grade coronary artery stenosis</td>
<td>9</td>
</tr>
<tr>
<td>Aortic aneurysm</td>
<td>6</td>
</tr>
<tr>
<td>Bypass graft occlusion</td>
<td>2</td>
</tr>
<tr>
<td>Pneumonic consolidation</td>
<td>2</td>
</tr>
<tr>
<td>Atelectasis</td>
<td>2</td>
</tr>
<tr>
<td>Mediastinal mass</td>
<td>2</td>
</tr>
<tr>
<td>Aortic dissection</td>
<td>1</td>
</tr>
<tr>
<td>Cardiac tumor</td>
<td>1</td>
</tr>
<tr>
<td>Lung tumor</td>
<td>1</td>
</tr>
<tr>
<td>Large hiatal hernia</td>
<td>1</td>
</tr>
<tr>
<td>Pulmonary metastasis</td>
<td>1</td>
</tr>
</tbody>
</table>

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In follow-up of creatinine levels, there was no evidence of contrast-induced nephropathy in any of the patients. In one patient renal failure developed 2 weeks after CTA but probably was the result of prolonged resuscitation after brainstem ischemia. Blood serum levels of cardiac enzymes on the day of the CT examination were available for comparison in 32 patients. Three of these patients had abnormal findings. Two patients had elevated muscle–brain type creatine kinase and troponin levels, which corresponded to two newly diagnosed cases of high-grade stenosis of the coronary arteries. One patient had only moderately elevated levels of muscle–brain type creatine kinase; her condition was diagnosed as a cardiac mass in the right ventricle. Continued follow-up after discharge revealed readmission of one patient for pneumonia, of which there had been no evidence 3 months earlier on the initial CT scan.

If the findings for the 14 patients whose clinical follow-up did not show diagnoses explaining chest pain are regarded as true-negative results, the sensitivity of CTA for identifying the origin of chest pain can be estimated at 92.7%. Calculation of specificity may be somewhat arbitrary for diagnoses such as pneumonic consolidation, atelectasis, and aneurysm, which can but may not in all cases be the cause of chest pain.

Coronary Arteries

Despite the high heart rates of our patients (71 ± 15 beats/min; range, 51–123 beats/min), only one examination of the right coronary artery resulted in image quality insufficient for diagnosis (grade 3). Apart from that, only minor motion artifacts were visible in 10 of the patients (grade 2, 18.5%; heart rate, 63–118 beats/min). In two patients, motion artifacts affected only the right coronary artery, and in one patient, only the left coronary system. These artifacts caused only minor impairment of image quality, and occlusion and high-grade stenosis were ruled out. Thus, overall the image quality rating was 1.2 ± 0.4.

Twenty-four patients had signs of severe atherosclerosis of the coronary arteries. High-grade coronary stenosis or occlusion (Fig. 2) was found in nine patients. Six of the lesions had been depicted on coronary angiograms obtained within 1 year before the CT examination. The other three were newly diagnosed and were confirmed at subsequent X-ray angiography. One of the patients had in-stent restenosis of the left circumflex coronary artery (segment 11) and underwent bypass surgery. One patient had high-grade stenosis of the right coronary artery, which was dilated and stented. The third patient had stenosis in the left anterior descending coronary artery (segments 7 and 8) and in the first diagonal branch (segment 9), and these segments were dilated.

In the comparison of coronary CTA with conventional coronary angiography as the standard of reference in the detection of significant (> 50%) stenosis, among 20 patients there were 16 true-positive results, including eight cases of occlusion; three false-positive results; and one false-negative (undergraded) result in the consensus interpretation of both radiologists. Thus sensitivity, specificity, and accuracy on a per-patient basis were 94%, 77%, and 87%, respectively. The positive predictive value was 84%, and the negative predictive value was 91%.

Interobserver agreement for the two independent blinded reviewers regarding presence or absence of clinically significant stenosis of the coronary arteries in each patient showed a kappa value of 0.81, indicating very good agreement. Agreement regarding number of significant stenoses per patient showed a kappa value of 0.62, corresponding to good agreement. Regarding wall irregularities with stenosis < 50%, the kappa value was 0.43 (moderate agreement). These vessel wall changes were not consistently described in conventional angiography reports, and therefore correlation was not possible.

Pulmonary Arteries

Pulmonary embolism was diagnosed in 10 patients (Figs. 1C and 3) and ruled out to the subsegmental level in the others. ECG gating proved useful in avoiding blurring of pulmonary arteries due to cardiac motion, enabling the ruling out of subsegmental embolism in the paracardiac pulmonary arteries. Minor motion artifacts of the paracardiac subsegmental pulmonary arteries adjacent to the left ventricle were found in two patients in whom there were also motion artifacts of the coronary arteries. One patient had secondary pulmonary hypertension due to chronic recurrent thromboembolism, which was correctly diagnosed with CTA and confirmed with conventional angiography.

Aorta

In one patient, type A dissection of the aorta was diagnosed (Fig. 2), and in six patients aortic aneurysm was diagnosed. ECG gating proved particularly useful in avoidance...
of the motion artifacts that often impair accurate assessment of the aortic root and the ascending aorta, especially in dissection and involvement of the coronary ostia. In none of the examinations did significant motion artifacts affect evaluation of the aortic root.

Discussion

A number of clinical studies have shown that in 27–45% of patients with acute chest pain, the pain is of cardiac origin. The studies also have shown that in approximately 28% of cases the pain is caused by ischemia and that approximately 50% of patients admitted have a noncardiac cause of the symptoms [13, 14]. The sensitivity of 12-lead ECG in identifying ischemia has been reported to be as low as 50% [15]. Early stress scintigraphy and stress echocardiography have been proposed for further evaluation of suspected ischemic pain without ECG changes, but these methods have only limited availability [16, 17]. In cases in which there is clinical suspicion of aortic dissection, CT findings of an alternative diagnosis for the presenting symptoms are only slightly less common than the finding of aortic dissection itself [18]. Moreover, patients with type A dissection may have ECG changes caused by modulation of coronary flow [19]. There also have been reports of uncommon ECG changes corresponding to symptoms during recurrent pulmonary embolism [20].

Gated CTA can be a useful clinical tool in the context of evaluation of acute chest pain, enabling exclusion of significant coronary stenosis and occlusion, especially in patients with inconclusive ECG findings or no signs of ischemia or infarction. If the symptoms are not characteristic of a specific cause, an ECG-gated scan covering the entire chest allows simultaneous assessment of many additional life-threatening differential diagnoses, such as pulmonary embolism, aortic dissection, spontaneous pneumothorax, and pneumatic consolidation. The focus of this study was to evaluate a protocol that allows simultaneous and fast assessment of the most important vascular regions of the chest in one scan and to determine whether sufficient image quality and diagnostic accuracy can be achieved in patients with acute chest pain.

Until recently, the scan times required for ECG-gated high-resolution CTA of the entire chest required breath-holds lasting more than 30 seconds. With CT scanners with faster gantry rotation times and additional detector rows, scanning time has decreased significantly, making ECG-gated examination of the entire chest feasible even for patients with moderate dyspnea. Our study showed that sufficient contrast enhancement of the pulmonary vessels, coronary arteries, and aorta can be achieved without excessive doses of contrast medium.

A major problem arising from faster volume coverage is contrast administration. As scan times shorten, higher injection rates are needed to achieve sufficient contrast with acceptable volumes of contrast material. We chose the ascending aorta as the region of interest for bolus tracking to ensure sufficient opacification of the coronary arteries [21]. Although it did not occur in our study, insufficient opacification of the pulmonary arteries can happen in patients with severe pulmonary congestion [22]. To address this problem, it may be helpful to use a test bolus for simultaneous evaluation of arrival and transition times of contrast medium in regions of interest in the pulmonary trunk and ascending aorta. It would be possible to adjust delay and amount of contrast agent to ensure sufficient opacification of both the pulmonary vessels and the aorta.

The radiation exposure of retrospectively ECG-gated CTA scans is higher than that of non-gated chest protocols. Therefore this protocol should be used only if there is a clinical indication for imaging of the pulmonary vessels and the coronary arteries, aorta, or both. On the other hand, our protocol allows evaluation of the entire chest in one scan and may therefore help to avoid additional diagnostic procedures. In our experience, a specific protocol with an increased pitch factor of 0.3 (compared with 0.2 in a standard CTA protocol for depiction of the coronary arteries) seems helpful for reducing radiation exposure, scanning time, and volume of contrast medium to approximately two-thirds those of a standard CTA protocol without significant changes in image quality. Given the average scan range of approximately 248

Fig. 2—75-year-old man with acute chest pain.
A, Axial CT image shows dissection (black arrow) of aortic root and high-grade stenosis (white arrow) of left anterior descending coronary artery.
B, Maximum intensity projection shows slightly angulated detailed view of stenosis of left anterior descending coronary artery.
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Fig. 3—84-year-old man with acute chest pain. Volume-rendered image of chest in left anterior view shows venous bypass grafts from ascending aorta to right coronary artery and to circumflex branch of left coronary artery (white arrows). Distal part of severely altered left anterior descending coronary artery has narrow lumen (black arrow). Course of occluded arterial bypass graft from left internal mammary artery to left anterior descending coronary artery is marked by clips (arrowheads).

mm, the estimated equivalent dose is approximately 6.9 mSv for this protocol (at a pitch of 0.3 and with ECG pulsing). According to the literature [23, 24], equivalent doses for alternative examinations can be estimated at approximately 3.2 mSv for pulmonary angiography, 1.2 mSv for ventilation–perfusion scintigraphy, and approximately 1.6–7 mSv (CT dose index volume, 19.4 mGy) for nongated CT pulmonary angiography. Roos et al. [25] cited doses of 3.65, 8.85, and 4.50 mSv for prospectively triggered, retrospectively gated, and nongated CTA of the aorta, respectively, covering a range of 15 cm. Equivalent doses of 5–7 mSv for retrospectively gated CTA examinations of the coronary arteries have been described [26], whereas conventional angiography requires an average dose of approximately 5 mSv [27]. Thus the dose required for the combined examination protocol is within the range of CT examinations of the individual vascular territories. This feature may contribute to reduced radiation exposure.

With the advent of MDCT, CTA has become a primary imaging tool for the examination of patients with suspected pulmonary embolism [28]. Higher resolution and faster acquisition times improve visualization of subsegmental pulmonary arteries [29–33]. Artifacts from cardiac motion compromise image quality, however, doubling or blurring paracardiac pulmonary arteries and bronchi and hindering assessment of emboli. Previous evaluations of ECG-gated chest scans for pulmonary embolism have been limited by prolonged scan times. To some authors [24], the additional information has not seemed worth the increase in scanning time and radiation exposure. In the evaluation of unclear chest pain, however, simultaneous assessment of coronary arteries and the ascending aorta may justify the disadvantages, especially because scanning time is only moderately prolonged with current techniques.

Patients with typical angina and known coronary artery disease should be examined with appropriate techniques such as X-ray coronary angiography. Our protocol, however, may help to exclude significant coronary stenosis in patients with atypical chest pain and normal creatine kinase and troponin levels. Studies with 16-MDCT have shown a high negative predictive value of MDCT angiography [7–9]. A problem of ECG-gated image acquisition in previous studies was the reduced image quality in patients with heart rates greater than 80 beats/min, because the diastolic data acquisition window became too short in approximately 25% of cases [34, 35]. However, with the shortened gantry rotation time of 0.33 seconds and an inherent temporal resolution of 165 and 83 milliseconds for single half-segment reconstruction and dual multisegment reconstruction, respectively, we obtained sufficient quality of images of the coronary arteries in almost all of our patients, although we did not use β-blockers to lower heart rates. Further studies are needed to evaluate the effect of faster rotation on coronary CTA of patients with higher heart rates.

Another frequent diagnostic problem in nongated CTA is assessment of aortic dissection, especially of the ascending aorta. This problem can be eliminated with ECG gating. We found no motion artifacts in the aortic root in our study. Roos et al. [25] found the advantages of ECG gating for this purpose, and with dedicated multiphase reconstruction, the aortic and mitral valves can be evaluated [36], which we did not address in this study. Some authors advocate use of an unenhanced scan for more reliable identification of intramural hematoma and hyperdense acute thrombi in the false lumen of dissected vessels. To limit radiation exposure, we chose not to acquire an unenhanced scan. If the clinical presentation of a patient suggests aortic dissection, an additional unenhanced scan may be appropriate.

Aortic aneurysm is the cause of acute chest pain in some patients but is an incidental finding in others. Evaluation of the dilated aortic wall and reliable measurement of the diameter profit from the absence of motion artifacts. The clinical significance of this finding has to be considered individually.

A limitation of this study was the inclusion criteria. We examined only patients referred by the emergency department for unclear chest pain, and this aspect of the study implies preselection of patients. For example, a patient with signs of myocardial infarction would have been referred immediately for invasive coronary angiography without undergoing CTA. This factor may explain the relatively high prevalence of pulmonary embolism in our patients. Another limitation was the lack of correlation with X-ray angiography for all patients and the long interval between invasive angiography and CTA in one half of our patients. It would be desirable to correlate the CTA findings with those of the respective standard examinations, such as ventilation–perfusion scintigraphy, aortic MRI, and quantitative coronary angiography. Doing so, however, would have been unethical because of radiation exposure, patient encroachment, and time.

In our experience, the protocol described in this study proved helpful in patients with acute chest pain of unclear cause. The three vascular territories (pulmonary arteries, coronary arteries, and aorta) were evaluated without limitation compared with dedicated protocols for the individual territories. Moreover, because of ECG gating, evaluation of the pa-
Cardiac pulmonary arteries and ascending aorta was improved by the absence of pulsation artifacts.

References


This article has been cited by:


2. Joseph P. Ornato, Michael R. Sayre, James I. Syrett. Chest pain and acute coronary syndromes 90-99. [Crossref]


5. Dong Han, Weihua Shi, Xiaoxia Chen, Jieli Zhou, Yong Yu, Xin Tian, Jing Chen, Mengting Liu, Taiping He. 2020. Optimal Monochromatic Energy Levels in Dual-Energy Spectral CT Pulmonary Angiography with Low Contrast Medium Dosage. Iranian Journal of Radiology 17:2. . [Crossref]

6. Borek Foldyna, Michael Lu, Udo Hoffmann. Cardiac Computed Tomography 481-510. [Crossref]

7. Rahatullah Muslem, Mohammed Ouhlous, Sakir Akin, Abd Alla Fares, Osama I. Soliman. Tricuspid Valve Disease: AComputed Tomographic Assessment 179-203. [Crossref]

8. Francesco Lavra, Luca Saba. 19. [Crossref]


11. Sebastian Faby, Thomas Flohr. Multidetector-Row CT Basics, Technological Evolution, and Current Technology 3-33. [Crossref]

12. Amelia M. Wnorowski, Ethan J. Halpern. Comprehensive CT Imaging in Acute Chest Pain 361-377. [Crossref]


15. Daniele Andreini, Eugenio Martusselli, Andrea Igoren Guaricci, Nazario Carrabba, Marco Magnoni, Carlo Tedeschi, Antonio Pelliccia, Gianluca Pontone. 2016. Clinical recommendations on Cardiac-CT in 2015. Journal of Cardiovascular Medicine 17:2, 73-84. [Crossref]

16. Amelia M. Wnorowski, Ethan J. Halpern. Comprehensive CT Imaging in Acute Chest Pain 361-377. [Crossref]

17. Thomas G. Flohr, Bernhard Schmidt. CT Technology for Imaging the Thorax: State of the Art 3-28. [Crossref]

18. Asim Rizvi, James K. Min. Cardiovascular CT in the Emergency Department 549-559. [Crossref]


22. Joseph P. Ornato, Michael R. Sayre, James I. Syrett. Chest pain and acute coronary syndrome 120-128. [Crossref]


71. Constanza J. Gutierrez, Edith M. Marom, Jeremy J. Erasmus, Edward F. Patz. Radiologic Imaging of Thoracic Abnormalities 25–37. [Crossref]

72. David M Hansell, David A Lynch, H Page McAdams, Alexander A Bankier. Mediastinal and aortic disease 881-1002. [Crossref]


74. E. Ronan Ryan, Ramon Martos, Ailbhe O’Neill, Charles Mc Creery, Jonathan D. Dodd. 2009. Coronary ostial involvement in acute aortic dissection: detection with 64-slice cardiac CT. *Clinical Imaging* **33**:6, 471–473. [Crossref]


76. Ronan P. Killeen, Jonathan D. Dodd, Ricardo C. Cury. 2009. Noncardiac findings on cardiac CT part I: Pros and cons. *Journal of Cardiovascular Computed Tomography* **3**:5, 293–299. [Crossref]


78. Amanda Wiant, Eric Nyberg, Robert C. Gilkeson. 2009. CT Evaluation of Congenital Heart Disease in Adults. *American Journal of Roentgenology* **193**:2, 388–396. [Abstract] [Full Text] [PDF] [PDF Plus] [Supplemental Material]


85. Lizhen Cao, Xiangying Du, Pengyu Li, Yaou Liu, Kuncheng Li. 2009. Multiphase contrast–saline mixture injection with dual–flow in 64-row MDCT coronary CTA. *European Journal of Radiology* **69**:3, 496–499. [Crossref]

86. Michael D. Shapiro. 2009. Is the “triple rule–out” study an appropriate indication for cardiovascular CT?. *Journal of Cardiovascular Computed Tomography* **3**:2, 100–103. [Crossref]

Coronary Arteries, Thoracic Aorta, and Pulmonary Vasculature in a Single Breath Hold. *Journal of Computer Assisted Tomography* 33:2, 225-232. [Crossref]


89. S.B. Heitner, S.W. Werns. 2009. Emergency Cardiac CT for Suspected Acute Coronary Syndrome: Qualitative and Quantitative Assessment of Coronary, Pulmonary, and Aortic Image Quality. *Yearbook of Critical Care Medicine* 2009, 49–51. [Crossref]


91. M. -A. Labeyrie, J. Marmursztejn, B. Daoud, S. Silvera, H. Gouya, O. Vignaux. Apport de l’IRM cardiaque dans la douleur thoracique aiguë 63–76. [Crossref]

92. Filippo Cademartiri, Ludovico La Grutta, Anselmo Alessandro Palumbo, Erica Maffei, Nico R. Mollet. Lesions of Proximal Coronary Arteries 241-250. [Crossref]


95. Thomas Flohr, Bernd Ohnesorge. From Sixteen Slices to Nowadays — Cardiothoracic Imaging with CT 3–22. [Crossref]

96. Patrick M. Donnelly, Udo Hoffmann. 2008. Assessment of acute chest pain by CT. *Current Cardiovascular Imaging Reports* 1:2, 87–95. [Crossref]


99. . Computed tomography in the emergency department 201-209. [Crossref]


110. Ram Duriseti. Using Influence Diagrams in Cost-Effectiveness Analysis for Medical Decisions . [Crossref]


112. Patrick M. Colletti. 2007. Cardiac Imaging: Radiologists Prepare, Participate, and Publish. American Journal of Roentgenology 189:6, 1271-1271. [Citation] [Full Text] [PDF] [PDF Plus]

113. Carsten Rist, Thorsten R. Johnson, Christoph R. Becker, Maximilian F. Reiser, Konstantin Nikolaou. 2007. New applications for noninvasive cardiac imaging: dual-source computed tomography. European Radiology Supplements 17:S6, 16-25. [Crossref]


115. Á. Franco-López. 2007. Tomografía computarizada multidetector de arterias coronarias: no se trata de una batalla campal, sino de un compromiso profesional. Radiología 49:6, 377-379. [Crossref]


119. J.P. Laissy. 2007. Faut-il proposer un examen TDM avec synchronisation ECG dans les urgences thoraciques ?. Journal de Radiologie 88:9, 1130-1131. [Crossref]

120. Raymond J. Gibbons, Philip A. Araoz, Eric E. Williamson. 2007. The Year in Cardiac Imaging. Journal of the American College of Cardiology 50:10, 988-1003. [Crossref]


125. Thorsten R. C. Johnson, Konstantin Nikolaou, Christoph R. Becker. Vascular: Extended Chest Pain Protocol 130-139. [Crossref]

126. Bernd Ohnesorge. Clinical Examination Protocols with 4- to 64-Slice CT 127-150. [Crossref]