

Interpretation of SPECT/CT Myocardial Perfusion Images: Common Artifacts and Quality Control Techniques¹

TEACHING POINTS

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Nuclear medicine has long played an important role in the noninvasive evaluation of known or suspected coronary artery disease. The development of single photon emission computed tomography (SPECT) led to improved assessments of myocardial perfusion, and the use of electrocardiographic gating made accurate measurements of ventricular wall motion, ejection fractions, and ventricular volumes possible. With the use of hybrid SPECT/computed tomography (CT) scanning systems, the cardiac functional parameters can be measured in a single imaging session. These recent advances in imaging technology have not only enhanced image quality but also improved diagnostic sensitivity and specificity in the detection of clinically relevant coronary artery disease. The CT-based attenuation maps obtained with hybrid SPECT/CT systems also have been useful for improving diagnostic accuracy. However, when attenuation correction and other advanced image data postprocessing techniques are used, unexpected artifacts may arise. The artifacts most commonly encountered are related to the characteristics either of the technology or of the patient. Thus, close attention to the details of acquisition protocols, processing techniques, and image interpretation is needed to ensure high diagnostic quality in myocardial perfusion studies.

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Abbreviation: ECG = electrocardiography

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Introduction

Attenuation correction methods have enhanced image quality and improved the sensitivity and specificity of myocardial perfusion imaging by limiting the effect of soft tissue attenuation. Computed tomography (CT)-based attenuation maps (μ maps) obtained with current-generation hybrid single photon emission computed tomography (SPECT)/CT systems represent a substantial improvement over traditional attenuation correction methods based on line source transmission. However, unexpected artifacts may arise with the use of attenuation correction methods at SPECT/CT myocardial perfusion imaging, and close attention to quality assurance is needed during image data postprocessing and in the reconstruction and interpretation of attenuation-corrected images. The article reviews the causes and appearances of artifacts commonly encountered at myocardial perfusion imaging with SPECT/CT, including artifacts related to postprocessing techniques and those related to the individual patient. Methods for correcting or preventing each of these artifacts are discussed in detail.

Radiotracers

Technetium ^{99m}Tc sestamibi and ^{99m}Tc tetrofosmin are the radiotracers most commonly used in myocardial perfusion imaging. These lipophilic cationic complexes cross the cell membrane by passive diffusion and localize in the mitochondria, binding to intramitochondrial proteins. As a result, they do not undergo a substantial redistribution like that of thallium 201-labeled compounds. Thus, the use of either ^{99m}Tc sestamibi or ^{99m}Tc tetrofosmin allows greater flexibility in the timing and duration of image acquisitions, and delayed or repeated imaging may be performed as needed. One important difference between ^{99m}Tc sestamibi and ^{99m}Tc tetrofosmin is that the latter is cleared more rapidly from the liver, especially if administered while the patient is resting or undergoing pharmacologic stress induction. Earlier hepatic clearance allows earlier imaging and lessens the likelihood of artifacts related to hepatic uptake.

Patient Preparation

At the authors' institution, all patients referred for myocardial perfusion imaging complete a focused cardiovascular history survey and undergo a physical examination immediately before imaging. Patients are questioned about their symptoms, including inciting factors and relieving factors, and are asked whether any change in

symptoms has occurred since their last visit to the referring physician, especially if signs of instability have developed. The patient's physical tolerance for various forms of stress testing should be assessed. The carotid pulses, pulmonary function, and cardiac function should be evaluated, and the lungs should be assessed for evidence of heart failure and pulmonary edema. The heart should be assessed for evidence of heart failure and severe or critical aortic stenosis.

Patients are instructed not to eat for 4 hours before perfusion imaging, to decrease splanchnic blood flow and radiotracer activity in the liver and bowel. Nondairy and noncaffeinated beverages may be consumed up to the time of imaging, but patients are instructed not to ingest caffeine for 12–24 hours before the imaging examination, because caffeine can blunt the effect of commonly used pharmacologic stress induction agents. Ideally, patients without previously documented coronary artery disease also would withhold consumption of β -blockers and calcium channel blockers for 24 hours before the start of imaging because these medications are known to reduce the sensitivity of stress perfusion imaging, whether stress is exercise induced or pharmacologically induced. Long-acting nitrates should be withheld the day of the imaging examination, if possible. However, it is best left to the referring physician to determine whether the patient can tolerate the withholding of these medications. When perfusion imaging is performed for risk stratification of patients who are undergoing medical therapy for known coronary artery disease, medications are not usually withheld.

Stress Induction Protocols

Myocardial perfusion imaging traditionally has been performed with rest-stress imaging protocols based either on a 2-day examination schedule, with the maximum radiotracer dose administered for rest and stress perfusion studies performed on different days, or a 1-day examination schedule, with a low dose of the radiotracer administered for rest imaging and a higher dose administered for stress imaging. Both rest-stress and stress-rest perfusion imaging protocols have been validated by the accumulated experience of many years. However, an advantage of using a stress-first protocol is that if the stress images are entirely normal, rest imaging need not be performed. The results of several studies performed in the past several years in large patient groups have confirmed that mortality rates after normal findings at stress-only perfusion imaging are similar to those after combined rest-stress perfusion imaging (1,2).

For patients who are unable to complete the standard exercise protocol for stress induction, regadenoson (Lexiscan; Astellas Pharma US, Deerfield, Ill) is the currently preferred pharmacologic stress induction agent. Regadenoson is a highly specific adenosine A_{2A} receptor agonist that acts as a coronary vasodilator and has very low affinity for the A_1 , A_{2B} , and A_3 receptors that are responsible for the major side effects of adenosine and dipyridamole. Side effects of the latter two agents may include depressed function of sinoatrial and atrioventricular nodes and possible atrioventricular node block (A_1), severe peripheral vasodilation and hypotension (A_{2B}), and bronchoconstriction that may be severe and life threatening (A_3) (3,4). Because regadenoson has little if any cross reactivity with the adenosine A_3 receptor responsible for bronchospasm, it is safer than intravenous adenosine and dipyridamole for use in patients with asthma or chronic obstructive pulmonary disease with a reversible component (5,6). However, caution is advised when using regadenoson in patients with bronchospastic airway disease, and bronchodilator therapy should be immediately available. Patients with moderate to severe bronchospasm at the time of the perfusion imaging study may require inhalation therapy with albuterol sulfate or a similar medication to minimize wheezing before the regadenoson infusion is administered (7). Dipyridamole and adenosine must be used with extreme caution in patients with even minimal wheezing, and such patients should receive prophylactic inhalation therapy if either of these stress-inducing pharmacologic agents is to be used. If adenosine is the only agent available and bronchospasm cannot be corrected with an inhalant, it is best to postpone the perfusion imaging study until the patient's pulmonary status has been medically optimized.

Regadenoson is administered intravenously at a dose of 0.4 mg, followed by a saline flush. The radiotracer ^{99m}Tc sestamibi (mean dose and standard deviation, 7.4 MBq [0.2 mCi] per kilogram body weight \pm 18.5 [\pm 0.5]) is injected 10–20 seconds after the saline flush. If dipyridamole is used instead of regadenoson, it is infused over a period of 4 minutes (dosage, 0.142 mg/kg/min), and the radiopharmaceutical is injected 3–4 minutes after the completion of the dipyridamole infusion. If adenosine is used instead, it is infused over a period of 6 minutes (dosage, 0.14 mg/kg/min), and the radiopharmaceutical is injected between 3 and 4½ minutes after the start of the adenosine infusion. All patients who receive regadenoson also receive 150 mg of intravenous aminophylline at least 3–4 minutes after the radiotracer injection, to prevent delayed side effects (8).

Aminophylline is also administered after dipyridamole but is not required after adenosine unless bronchospasm occurs, because of the extremely short biologic half-life of adenosine (10 seconds). Whenever possible, patients undergoing pharmacologic stress induction with a vasodilator also complete a limited exercise protocol tailored to their physical ability. The combination of walking with pharmacologic induction of stress has been shown to decrease medication-related side effects and reduce gastrointestinal uptake of the radiotracer, and it may also increase the diagnostic sensitivity of the examination (9–12).

Image Acquisition Protocol

After a delay, the duration of which depends on the stress induction protocol (15 minutes with exercise, 45–60 minutes with the use of a pharmacologic agent), the patient undergoes electrocardiography (ECG)-gated myocardial perfusion imaging with a SPECT/CT system (Symbia T16 Truepoint; Siemens, Hoffman Estates, Ill]). The patient is positioned supine on the table with his or her arms raised straight above the head and a nylon belt wrapped snugly around the abdomen to minimize respiratory motion. First, low-dose (0.2–0.4-mSv) end-tidal expiratory breath-hold CT is performed (110 kVp, 15 mAs) to obtain an attenuation map. ECG-gated SPECT is then performed with a frame rate of eight to 16 frames per cardiac cycle, with forward-backward gating allowing rejection of premature and postpremature heartbeats by using an acceptance window of 20%–30% R-R (ie, beat-to-beat) variation in cycle length on the ECG tracing. If any beats are rejected, each projection should be acquired for the same number of accepted beats or the same acceptance time interval. A symmetric 15% energy window is centered at 140 keV, the photopeak energy of ^{99m}Tc sestamibi. Low-energy high-resolution parallel hole collimators are used. Acquisition parameters include a 90° rotation (with use of two camera heads) and a noncircular orbit with step-and-shoot acquisitions. The SPECT images are then reconstructed to fit a digital matrix of 128 × 128 pixels. Images without attenuation correction are reconstructed by using the filtered back projection method, and attenuation-corrected images are reconstructed by using an iterative ordered subset expectation maximum algorithm and filtering (10 iterations, eight subsets; 9.6-mm Gaussian filter). The myocardial perfusion imaging dataset is carefully coregistered with the CT attenuation map to produce the attenuation-corrected images (Fig 1).

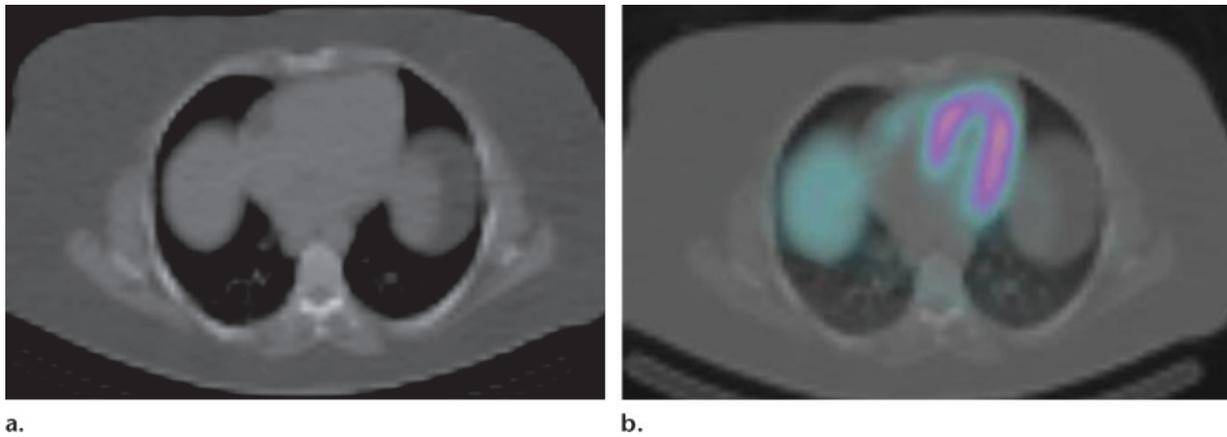


Figure 1. Quality assurance comparison of the CT attenuation map before (a) and after (b) coregistration with the raw SPECT image dataset (represented in color) is important to avoid artifacts on the final reconstructed SPECT/CT images. In this case, the two datasets are properly coregistered.

Figure 2. (a) Single frame from a rotating cinematic display of a raw SPECT image dataset shows normal physiologic activity of the radiotracer in the heart (arrow), liver (light area to the left of the heart, mostly between the two white lines), and bowel (light areas below the white lines). (b) Sinogram shows a smooth, continuous contour, with no sign of disruption by patient motion.

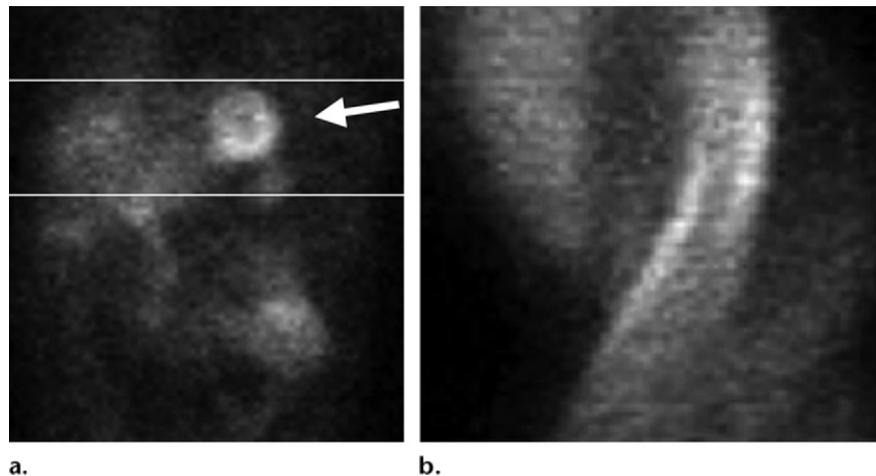


Figure 3. Single frame from a rotating cinematic display of a raw SPECT image dataset demonstrates abnormal uptake of ^{99m}Tc sestamibi in the left breast (arrow). Although this finding is nonspecific, it is highly suggestive of the presence of a breast malignancy, which was confirmed at biopsy. It is important to review the raw datasets for abnormal areas of extracardiac uptake of ^{99m}Tc sestamibi.

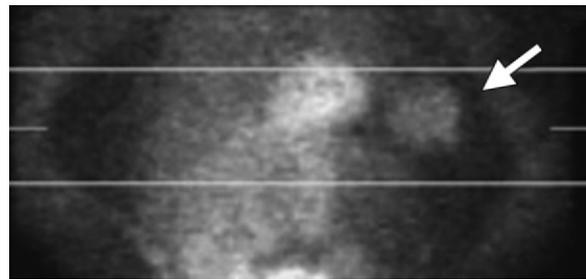


Image Display

Before interpreting the SPECT/CT perfusion images, the radiologist should complete several important preliminary steps for quality control. First, the raw datasets should be reviewed in cinematic display to determine whether any artifact due to patient movement or respiratory motion or any extracardiac uptake is present (Fig 2). Extracardiac radiotracer activity can degrade the quality of cardiac perfusion images; however, it also may allow the detection of unsuspected disease processes. Although uptake of ^{99m}Tc

sestamibi and ^{99m}Tc tetrofosmin is nonspecific, malignancies such as lymphoma and breast cancer have been detected as regions of extracardiac radiotracer activity at perfusion imaging (Fig 3). The sinogram also may be reviewed for extracardiac uptake (eg, in the lungs or esophagus) and motion-related artifact, which is manifested as discontinuities or breaks in the normally smooth curvature of the sinogram (13).

Next, the ECG-gated stress-only images and stress-rest images obtained with and without

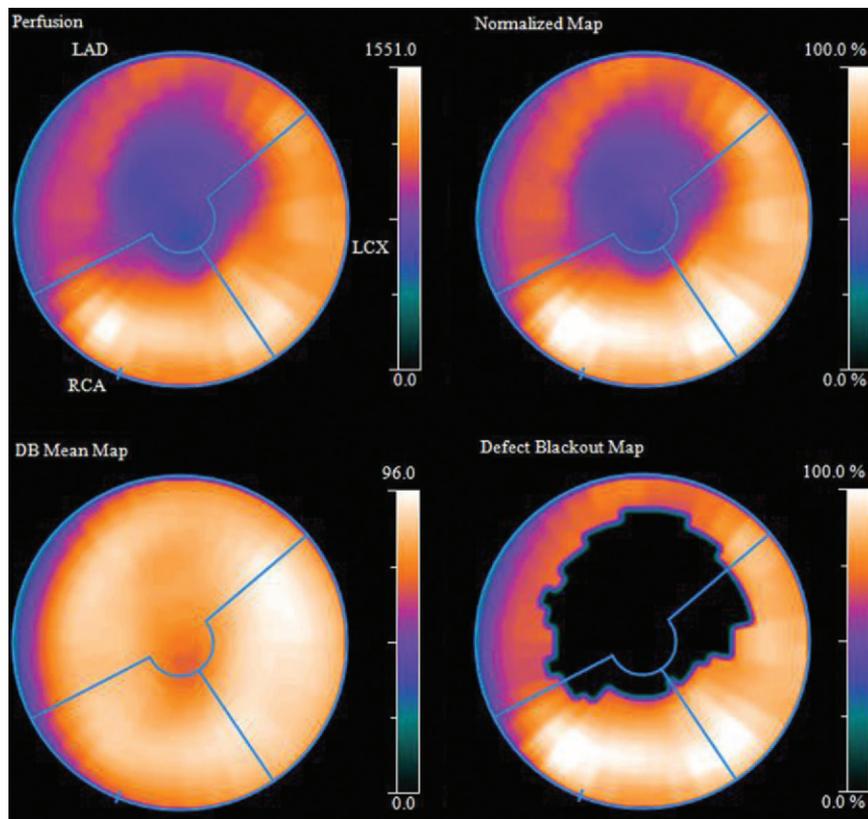


Figure 4. Polar maps show abnormal left ventricular myocardial perfusion in the territory of the left anterior descending coronary artery. The maps provide a two-dimensional view of the entire three-dimensional left ventricular myocardium, which is segmented (blue radial lines) into the territories of the left anterior descending (*LAD*), left circumflex (*LCX*), and right coronary (*RCA*) arteries. The central region represents the cardiac apex, and each ring of activity proceeding outward from the center is a step closer to the base (mitral valve plane). Perfusion map (upper left) represents the raw dataset from the perfusion study, with counts of radiotracer activity (from 0 to 1551, the peak count in this heart) shown in the color scale. Normalized map (upper right) shows activity counts from the perfusion map that have been normalized to 100% of the peak counts in the heart so that they can be compared with the counts in a database of maps from subjects with normal perfusion. Database (*DB*) mean map (lower left) shows the mean distribution of activity from the normal database cases against which the normalized counts from this individual patient will be compared. Defect blackout map (lower right), the result of this comparison, is created by blacking out all sample locations from the normalized map that show activity more than 2.5 standard deviations below the database norms.

attenuation correction are displayed in both traditional cardiac planes and as polar maps (Fig 4). Polar maps are two-dimensional displays of the three-dimensional distribution of radiotracer activity in the left ventricle. A single polar map shows quantified perfusion data for the entire left ventricle, which typically comprises approximately 500 data points of equal geometric volume. The center of the polar map represents the cardiac apex. As the eye moves outward from the center of apical activity, one contoured color-coded “ring” at a time, areas of the left ventricle that are closer to the base of the heart are seen; the cardiac base and mitral valve plane compose

the outermost region shown on the polar map. Myocardial perfusion values displayed on polar maps are normalized to the region of myocardium that has the highest counts. Each data point on the polar map is assigned a number and color corresponding to the radiotracer activity at that point, with activity being calculated as a percentage of the maximal left ventricular uptake (normalized). The normalized map thus obtained is then compared with a database of normalized polar maps previously obtained in subjects with

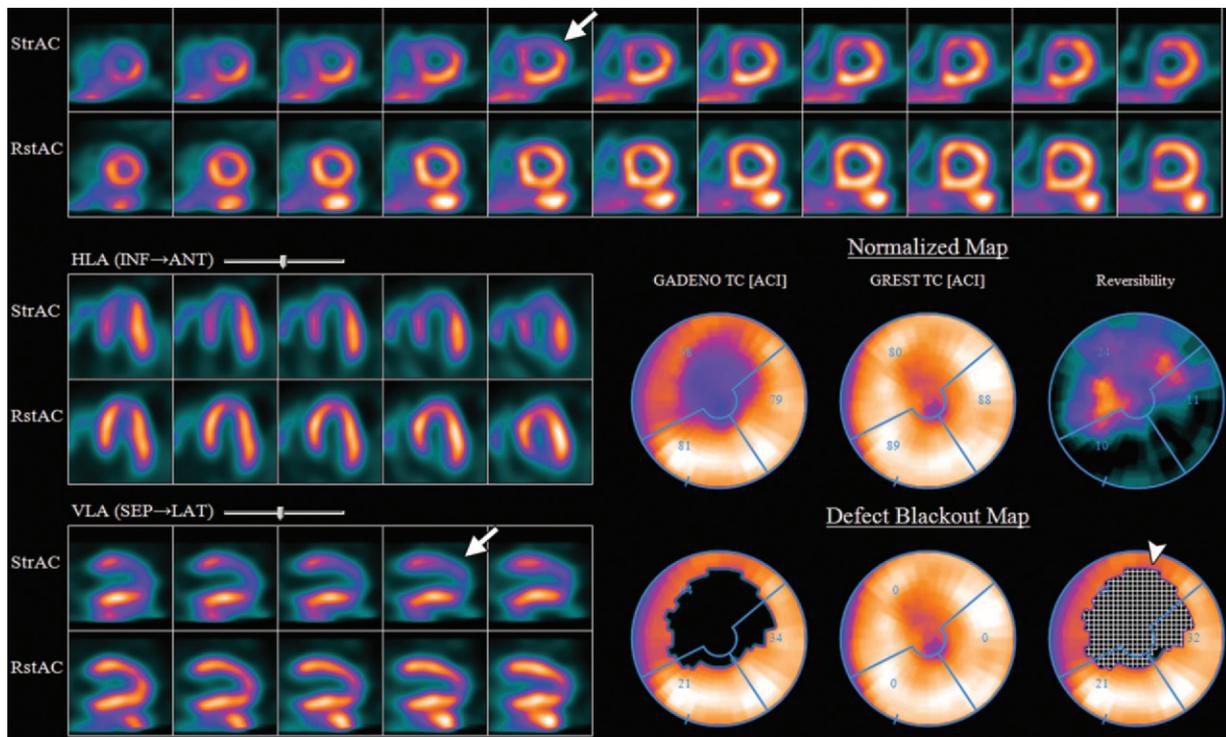


Figure 5. Summary screen from an attenuation-corrected stress (*StrAC*)-rest (*RstAC*) myocardial perfusion imaging examination performed with SPECT/CT shows a large reversible cardiac perfusion defect in the territory of the left anterior descending artery (ie, the anterior, septal, and apical walls) (arrows). Cross-hatching on the defect blackout map is indicative of a reversible perfusion defect (arrowhead). *ACI* = attenuation-corrected images, *GADENO TC* = ECG-gated stress imaging with regadenoson and a ^{99m}Tc -labeled tracer, *GREST TC* = ECG-gated rest imaging with a ^{99m}Tc -labeled tracer, *HLA* (*INF* → *ANT*) = horizontal long axis (inferior to anterior), *VLA* (*SEP* → *LAT*) = vertical long axis (septum to lateral wall).

verified normal left ventricular perfusion (14), from which the means and standard deviations of radiotracer activity in each of 500 sampled data points have been calculated.

Image Interpretation and Reporting

The stress and rest images displayed in the traditional cardiac planes may be reviewed separately from or simultaneously with the normalized polar map and database comparison map. The finding on stress images of a perfusion defect in a region that appears normal on rest images (ie, a reversible defect) is suggestive of myocardial ischemia (Fig 5). The finding on stress images of a perfusion defect that appears identical on rest images (ie, a fixed defect) could be either an attenuation artifact or an area of myocardial infarction (Fig 6). **ECG-gated stress images are often helpful for differentiating between the two: An area of infarction exhibits abnormal wall motion and wall thickening, whereas an attenuation artifact shows normal wall motion and normal wall thickness.** However, the distinction between the two may be less visible in the presence of diffuse systolic dysfunction

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produced by an underlying myopathic process. Attenuation-corrected stress and rest images are of great value in such cases because they do not show a defect that is an attenuation artifact.

Polar map displays and semiquantitative segmental scoring have greatly improved the detection and characterization of perfusion defects at myocardial perfusion imaging. The most frequently used polar map display is the so-called blackout map. On blackout maps, any sample locations of the individual patient's normalized polar map that have perfusion values below a designated threshold defining abnormality are displayed in black, while areas with perfusion values above this threshold retain their normalized color intensity. A designated threshold of 2.5 standard deviations below the normal database mean for each sample location is commonly used to identify perfusion defects. Areas of abnormal perfusion on stress images that do not meet the threshold for abnormal perfusion on rest images are automatically depicted with superimposed cross-hatching, which indicates the reversible nature of the perfusion defect. Last, a segmental scoring map can be generated from which a summed stress score, summed rest score, and summed difference score can be calculated. For segmental scoring, the left

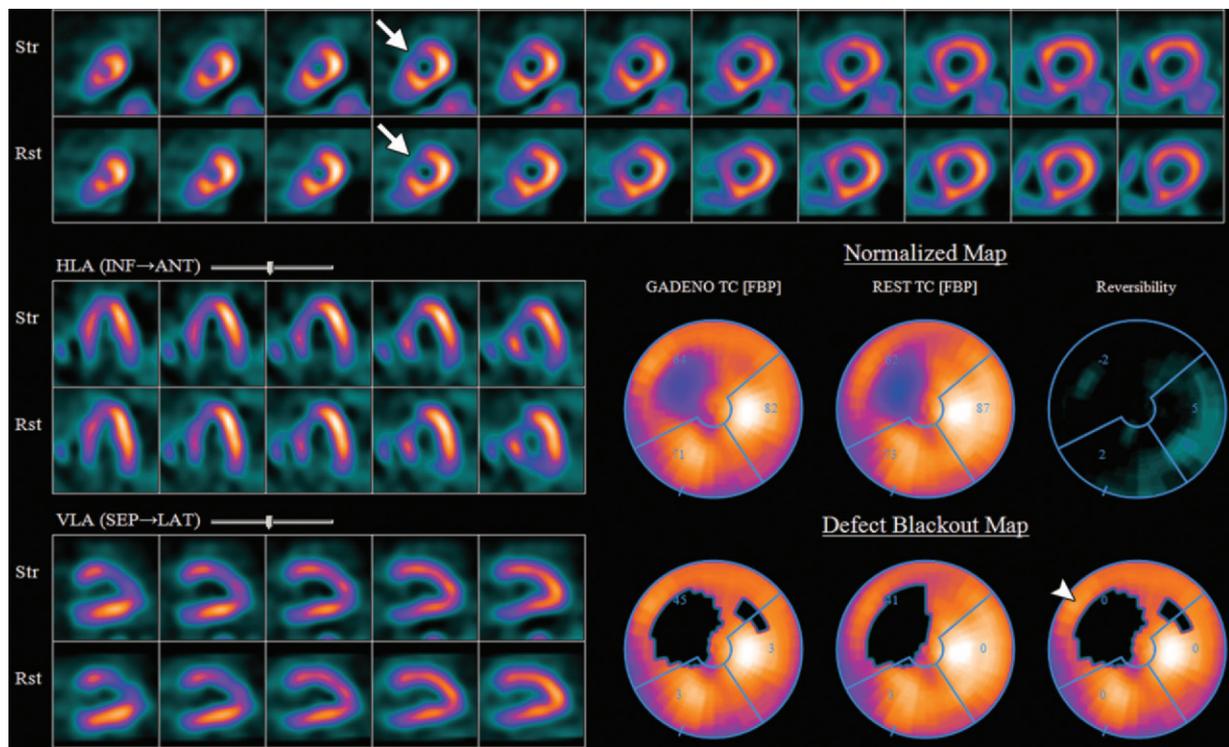


Figure 6. Summary screen from stress (*Str*)-rest (*Rst*) myocardial perfusion imaging performed with SPECT/CT. Perfusion images and polar maps demonstrate a large fixed anteroseptal perfusion defect, a finding indicative of an infarct in the territory of the left anterior descending artery (arrows). Defect blackout map shows a blackened region without cross-hatching (arrowhead), a feature indicative of a fixed perfusion defect (infarction). *FBP* = filtered back projection images, *GADENO* = *GADENO TC* = ECG-gated stress imaging with regadenoson and a ^{99m}Tc-labeled tracer, *HLA (INF → ANT)* = horizontal long axis (inferior to anterior), *REST TC* = rest imaging with a ^{99m}Tc-labeled tracer, *VLA (SEP → LAT)* = vertical long axis (septum to lateral wall).



Figure 7. Diagrams show the summed stress score (*SSS*), summed rest score (*SRS*), and summed difference score (*SDS*) from the same SPECT/CT myocardial perfusion imaging examination as in Figure 6. A summed stress score of 12 indicates an intermediate risk for a hard cardiac event over the subsequent 12 months. Summed stress scores of less than 3 are considered normal, whereas scores of 4–7, 8–12, and 13 or higher are indicative of low, intermediate, and high risk for a hard cardiac event.

ventricle on a polar map display is divided into 17 segments of equal volume, each of which is assigned a perfusion score between 0 and 4 (Fig 7). A score of 0 represents no significant difference between the patient’s stress perfusion data and the database norm. A score of 1 represents an equivocal or mild reduction in perfusion, 2 represents moderately reduced perfusion, 3 represents

severely reduced perfusion, and 4 indicates absent perfusion. The summed stress score for the left ventricle then is used to determine the risk for a future hard cardiac event (15). It must be emphasized that the polar maps do not replace perfusion images in the traditional cardiac planes but instead

Guidelines for Interpreting and Reporting Findings at Myocardial Perfusion Imaging**Perfusion defect size**

- Small (<10% of total left ventricular volume)
- Moderate (10%–20% of total left ventricular volume)
- Large (20%–40% of total left ventricular volume)
- Extensive (>40% of total left ventricular volume)

Perfusion defect severity (semiquantitative segmental scoring)

- Mild (<40% decrease from database norm; score of 1 or 2)
- Moderate (40%–60% decrease from database norm; score of 2)
- Severe (>60% decrease from database norm; score of 3)
- Absent perfusion (no activity; score of 4)

Perfusion defect location

- Cardiac wall (anterior, septal, inferior, lateral, or apical)
- Expected coronary artery involvement

Perfusion defect reversibility indicators

- Cross-hatching of the perfusion defect on the stress image–based polar map
- Improvement by 2 points or more in the semiquantitative segmental score, or an absolute segmental score of 0 or 1, on rest images

Risk for future hard cardiac events

- Normal risk (summed stress score, 0–3)
- Low risk (summed stress score, 4–7)
- Intermediate risk (summed stress score, 8–12)
- High risk (summed stress score, >12)

Additional cardiac findings

- Left ventricular wall motion and function (normal, hypokinetic [mildly, moderately, or severely], akinetic, or dyskinetic)
- Cardiac chamber size
- Right ventricular perfusion and function
- Presence of left ventricular dilatation during stress, transient ischemic dilatation

Extracardiac findings (radiotracer activity in adjacent tissues or organs)

are complementary, promoting more accurate and more consistent reporting of myocardial perfusion studies. The interpreting physician should carefully review both the images and the polar maps, comparing the findings on both, and if differences exist, should reconcile them before making a final determination.

When a perfusion defect is identified, its location, size, severity, and reversibility must be reported. Consistency in reporting can be of great value to referring clinicians and may be especially important in cases where previous perfusion imaging studies are available for comparison. Characterization of the size and severity of a defect can be subjective, varying between interpreting physicians, but the use of a quantitative software program along with predetermined size and severity criteria can enhance the consistency of interobserver and intraobserver interpretations and help standardize the reporting of perfusion

defects. The location of the defect should be described in regard to the left ventricular wall and the coronary vascular territory likely to be involved. Finally, the degree of reversibility should be described. If an area of infarcted myocardium with a fixed defect has perfusion greater than 50% of the database norm, it is considered to be at least partially viable (16).

In addition to the perfusion data, a complete nuclear cardiology report includes several other components. The cardiac chamber size, left ventricular wall motion, and right ventricular perfusion and wall motion should be reported. Stress-induced transient ischemic dilatation, a finding that is indicative of severe and extensive coronary artery disease and a high risk for a hard cardiac event, also should be reported. As previously discussed, any abnormal extracardiac uptake, although it may be nonspecific, should be included in the report. The type of stress protocol used should be specified. If an exercise protocol was used, the total exercise time, peak exercise heart rate and blood pressure, doubled product of the

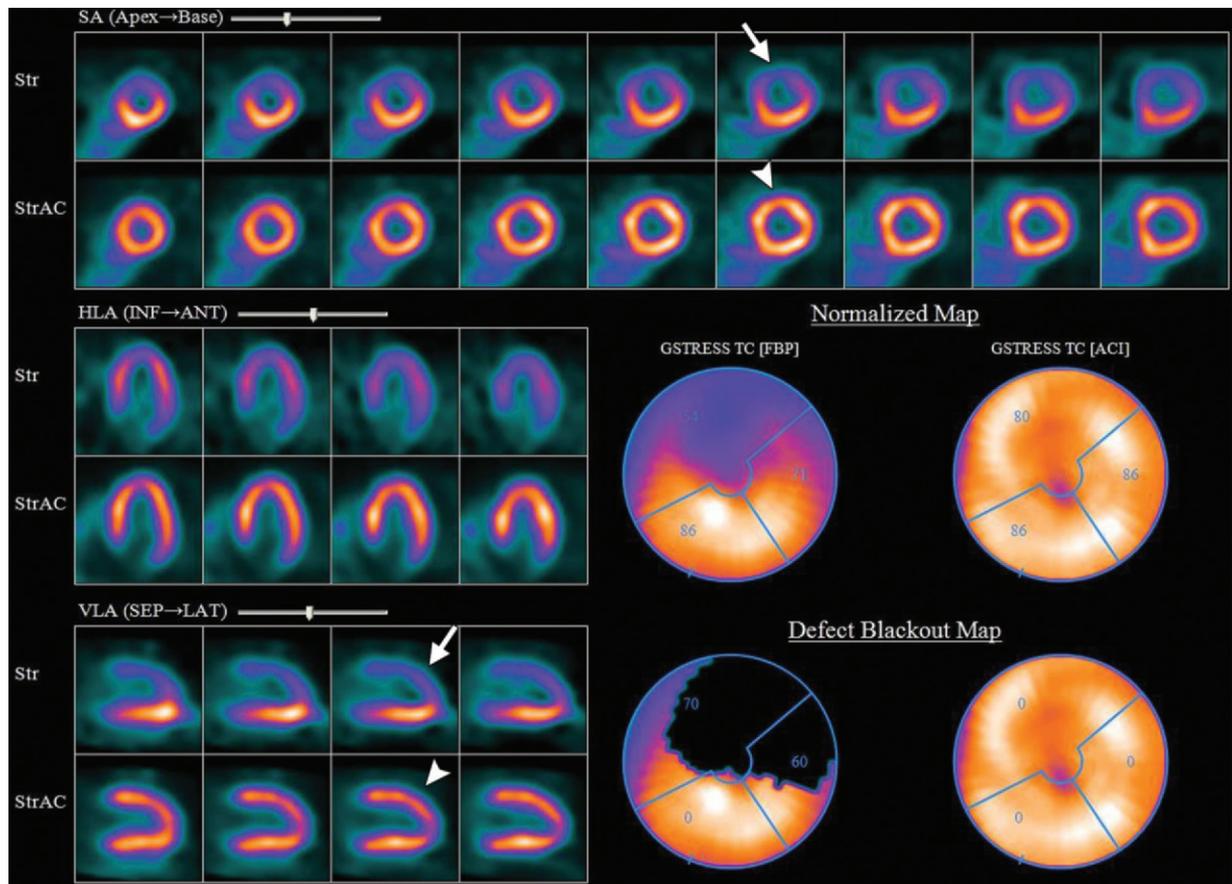


Figure 8. Summary screen from stress-only myocardial perfusion imaging performed with SPECT/CT in a 380-pound female patient shows a large apparent perfusion defect in the anterolateral myocardial wall (arrows) on images obtained without attenuation correction (*Str*), whereas attenuation-corrected images (*StrAC*) show no evidence of a defect at this site (arrowheads). These findings are indicative of a soft tissue attenuation artifact that was eliminated with attenuation correction. *ACI* = attenuation-corrected images, *FBP* = filtered back projection images, *GSTRESS TC* = ECG-gated stress images obtained with a ^{99m}Tc -labeled tracer, *HLA* (*INF* → *ANT*) = horizontal long axis (inferior to anterior), *SA* = short axis, *VLA* (*SEP* → *LAT*) = vertical long axis (septum to lateral wall).

peak heart rate and the systolic blood pressure used for attenuation correction, metabolic equivalent of task (the ratio obtained by dividing the rate of energy consumption during physical activity by a reference metabolic rate or the rate of energy consumption during rest), relevant changes in the ECG tracing, and chest pain should be reported. The criteria used for interpreting and reporting findings at myocardial perfusion imaging at the authors' institution are summarized in the Table.

Attenuation Correction and Artifacts

Attenuation of photons within the body has long been recognized as a major factor limiting the specificity of SPECT for the detection of myocardial perfusion defects. The impact of attenuation artifacts on the quality of the final reconstructed images depends on the attenuation characteristics of the tissues imaged and the energy of the radiotracer. Various attenuation correction methods have been used. When used in conjunction

with quantitative analysis, they can significantly increase the specificity of SPECT myocardial perfusion imaging.

Artifacts of Soft Tissue Attenuation

Soft tissue attenuation in the breast is a relatively common source of artifactual decreases in radiotracer activity in the anterior myocardial wall and may affect the depiction of activity in the septal and lateral walls as well, depending on the individual patient's body habitus (Fig 8). If the breast is in the same position during stress and rest imaging, the apparent perfusion defect will be present on both sets of images. If the ECG-gated SPECT perfusion images in such cases demonstrate normal wall motion and normal wall thickness, the apparent fixed defect is an artifact of soft tissue attenuation instead

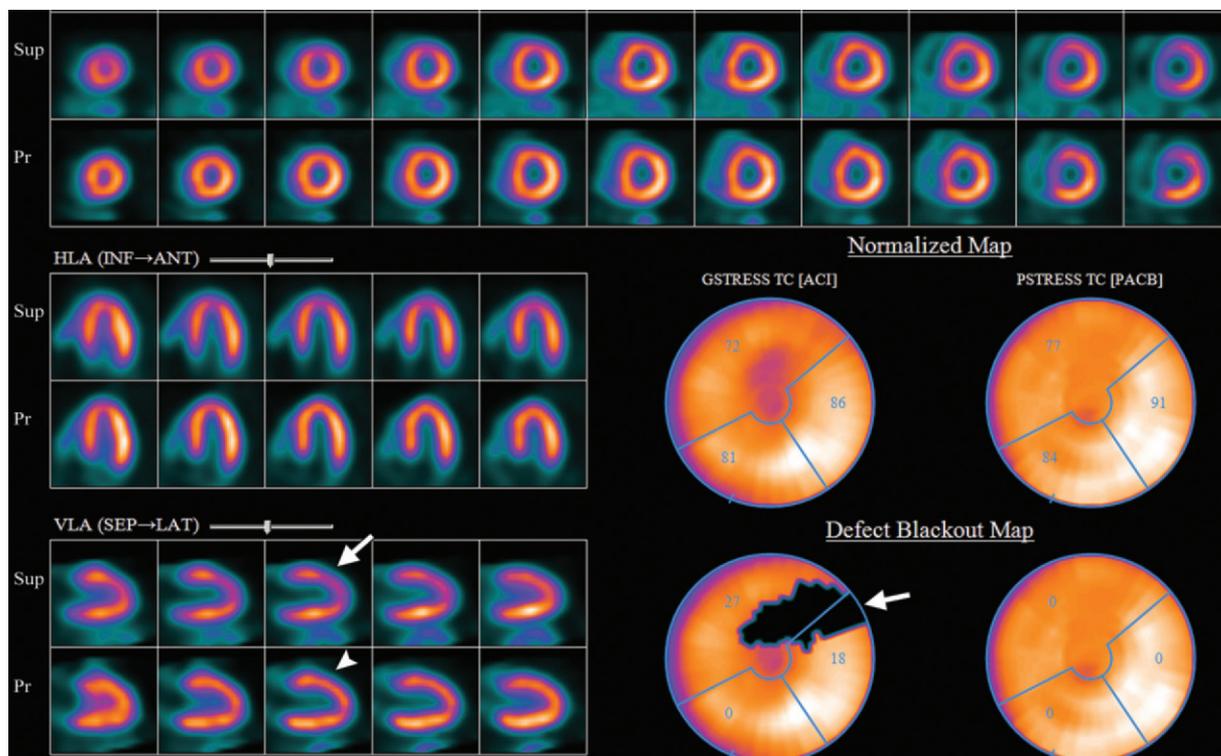


Figure 9. Summary screen from attenuation-corrected stress-only myocardial perfusion imaging performed with SPECT/CT in a normal subject shows different results with the subject supine (*Sup*) and prone (*Pr*): A moderate-sized apparent perfusion defect is seen in the anterior myocardial wall on supine images (arrows), whereas perfusion appears normal at this site on prone images (arrowhead). The apparent perfusion defect seen in this case is an artifact of soft tissue (breast) attenuation. *GSTRESS TC [ACI]* = supine ECG-gated stress imaging with a ^{99m}Tc -labeled tracer (attenuation-corrected images), *HLA (INF → ANT)* = horizontal long axis (inferior to anterior), *PSTRESS TC [PACB]* = prone free-breathing stress imaging with a ^{99m}Tc -labeled tracer (attenuation-corrected images), *VLA (SEP → LAT)* = vertical long axis (septum to lateral wall).

of an area of myocardial infarction. Additional clues to the artifactual nature of such a defect may include a noncoronary distribution of the abnormality and the observation of large, dense breasts at cinematic review of the raw images.

The inferior myocardial wall is a common site of fixed or variable attenuation artifacts produced by the left hemidiaphragm. Again, if no perfusion defect is present, the ECG-gated SPECT perfusion images demonstrate normal wall motion and normal wall thickness, confirming the artifactual nature of the abnormalities.

With use of an attenuation correction method such as a low-dose breath-hold CT scan obtained on a hybrid SPECT/CT system, a substantial number of these artifacts can be corrected (17). Attenuation-corrected images from a particular patient then can be compared both qualitatively and quantitatively with attenuation-corrected images in databases from patients with normal

cardiac perfusion. In addition, if breast attenuation degrades the quality of cardiac perfusion images, the imaging examination can be repeated with the patient in the prone position. Prone positioning of the patient may be helpful because it changes the position of the breast with respect to the heart and may decrease the degree of soft tissue attenuation (Fig 9).

Artifacts of Subdiaphragmatic Radiotracer Activity

Because of the hepatobiliary excretion of ^{99m}Tc -labeled radiotracers, prominent subdiaphragmatic activity may be seen in organs adjacent to the heart, predominantly the liver and bowel but also occasionally the stomach. Subdiaphragmatic radiotracer activity can affect myocardial perfusion imaging in several ways: First, scatter radiation from the radiotracer can lead to an appearance of increased perfusion in the inferior myocardial wall that might mask a true perfusion defect in this region, especially when the effect of scatter

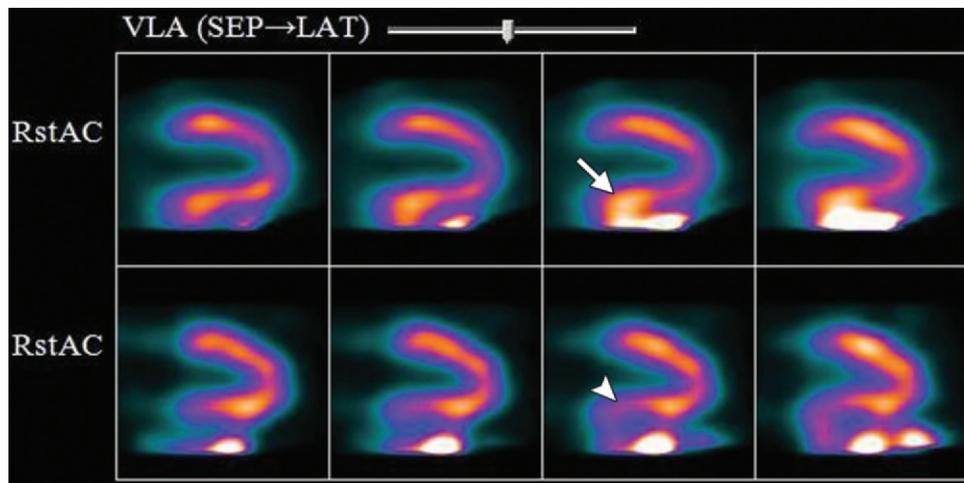


Figure 10. Attenuation-corrected resting myocardial perfusion images obtained with SPECT/CT show radiotracer activity in the bowel (arrow), a feature that masks the inferior wall defect evident on delayed images (arrowhead). *VLA (SEP → LAT)* = vertical long axis (septum to lateral wall).

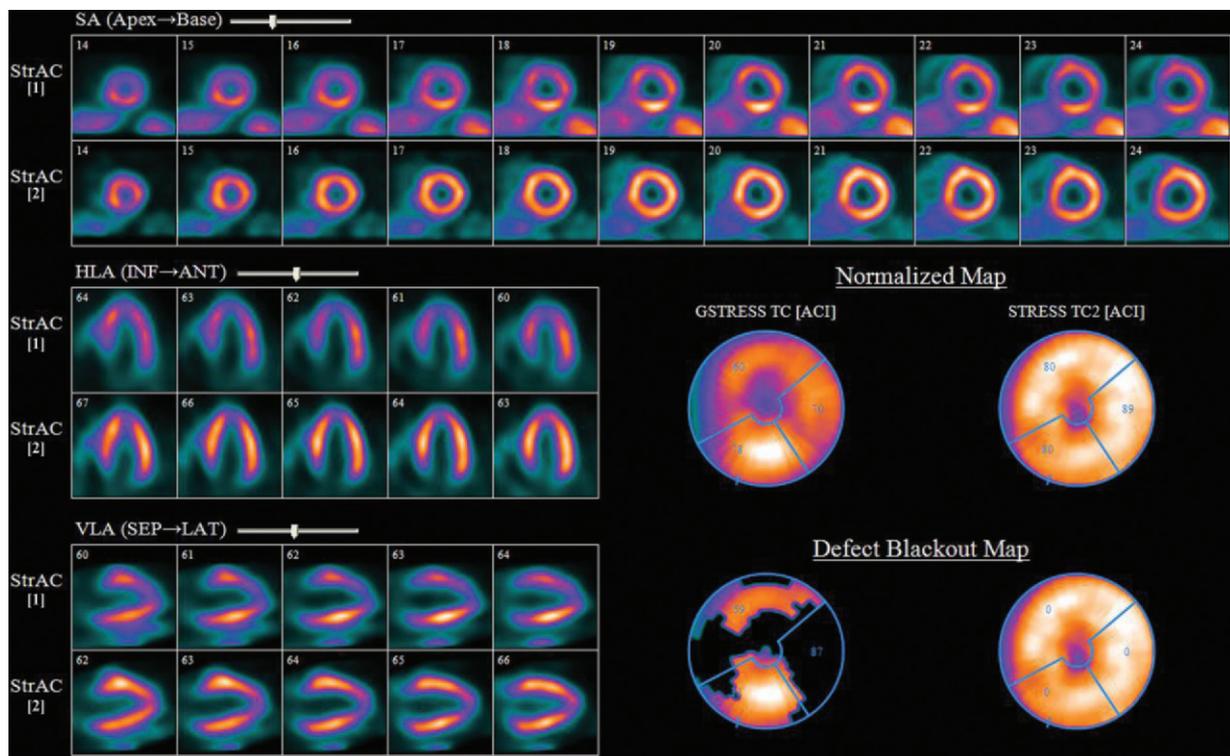
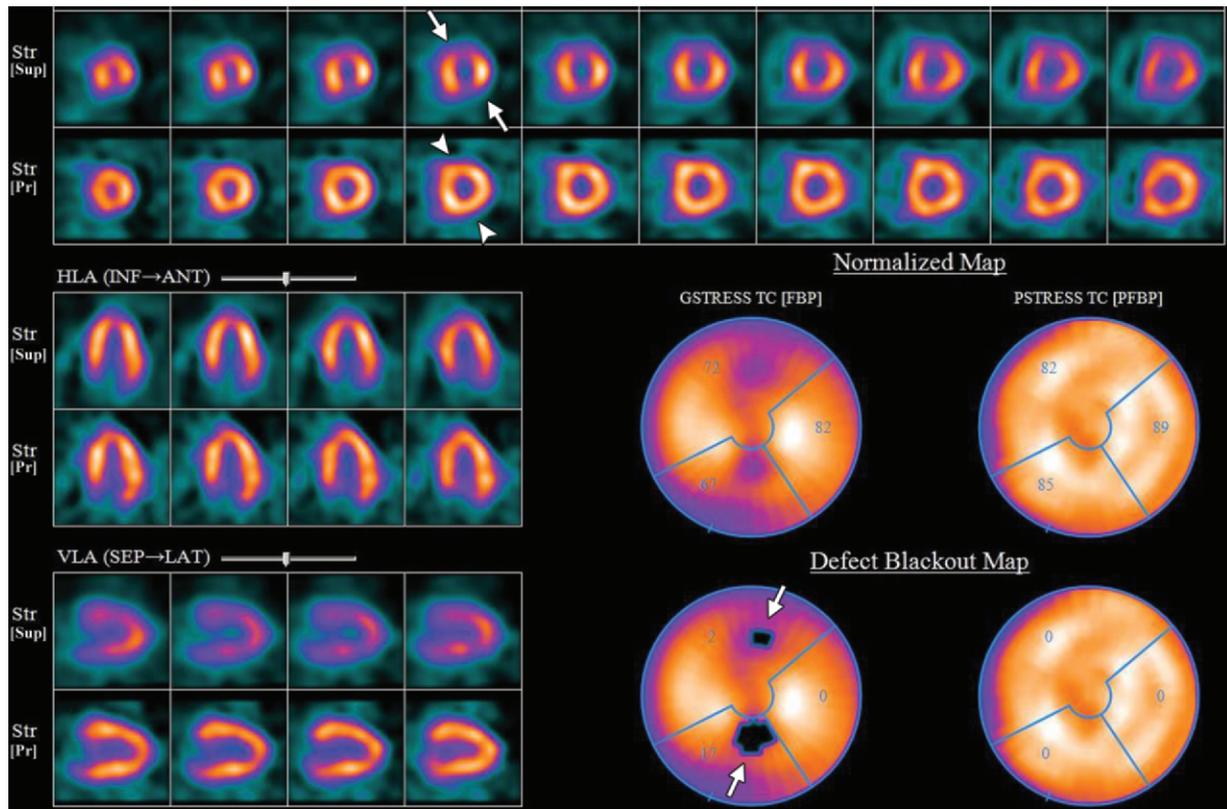


Figure 11. Summary screen from an attenuation-corrected stress myocardial perfusion imaging examination (*StrAC[1]*) performed with SPECT/CT shows an extensive artifact in the inferior wall on images and polar maps. The artifact was caused by normalization errors produced by subdiaphragmatic scatter radiation. Repeat imaging (*StrAC[2]*) after clearance of the radiotracer from abdominal organs showed normal perfusion at the site of the apparent defect. *ACI* = attenuation-corrected images, *GSTRESS TC* = ECG-gated stress imaging with a ^{99m}Tc-labeled tracer, *HLA (INF → ANT)* = horizontal long axis (inferior to anterior), *SA* = short axis, *STRESS TC2* = delayed stress imaging after clearance of the radiotracer from abdominal organs, *VLA (SEP → LAT)* = vertical long axis (septum to lateral wall).

is combined with partial volume effects (Fig 10). As mentioned earlier, the myocardial perfusion values displayed on polar maps are normalized to the region of myocardium that has the highest count of radiotracer activity. If the highest count is artificially elevated because of scatter from subdiaphragmatic locations or superimposition of sub-

diaphragmatic radiotracer activity on the inferior myocardial wall, the remainder of the left ventricle may appear to have relatively low activity simulating an extensive perfusion defect (Fig 11).

Figure 12. (a) Summary screen from a stress-only myocardial perfusion imaging examination performed with SPECT/CT shows small perfusion defects in the anterior and inferior walls (arrows) on images and maps obtained with the patient supine (*Str [Sup]*), and normal perfusion (arrowheads) on repeat images obtained with the patient prone (*Str [Pr]*). *GSTRESS TC [FBP]* = supine ECG-gated stress imaging with a ^{99m}Tc -labeled tracer and filtered back projection, *HLA (INF \rightarrow ANT)* = horizontal long axis (inferior to anterior), *PSTRESS TC [PFBP]* = prone free-breathing stress imaging with a ^{99m}Tc -labeled tracer and prone filtered back projection, *VLA (SEP \rightarrow LAT)* = vertical long axis (septum to lateral wall). (b) Three frames from the cinematic display of raw datasets obtained during supine perfusion imaging show substantial cardiac motion. Imaging with the patient prone helps decrease cardiac motion-related artifacts.



a.



b.

Artifacts related to subdiaphragmatic radiotracer activity can be difficult to eliminate, but several options exist. The image acquisition may be repeated after a delay to allow clearance of the radiotracer from regions adjacent to the heart (18). As with soft tissue attenuation artifacts, repeat imaging with the patient in the prone position can help minimize artifacts caused by subdiaphragmatic radiotracer activity because the distance between the heart and the subdiaphragmatic organs may be decreased (19,20). Last, for patients who are unable to achieve symptom-limited maximal exercise-induced stress, it may be helpful to combine the administration of a vasodilator with a low-level exercise protocol tailored to the abilities of the individual patient. The additional exercise-induced stress, even that induced by low-level exercise, may prevent subdiaphragmatic activity by reducing splanchnic blood flow to the viscera (21).

Artifacts of Patient Motion

Patient motion, most frequently that related to respiration, is one of the most common sources of artifacts at myocardial perfusion imaging. Motion-related artifacts are best detected by carefully reviewing the raw images with a rotating cinematic display. Evaluation of the sinogram for discontinuities may be especially useful for detecting movement. In the presence of a motion artifact, the heart will be seen in different locations on adjacent SPECT projection images. When the raw projection data are back-projected onto the volume reconstruction matrix, there will be inconsistencies that the algorithm cannot correct for, and the resultant artifactual defects may mimic perfusion abnormalities (22). **If a substantial amount of motion is detected during a study with a ^{99m}Tc -labeled radiotracer, repeat imaging can be performed without a second radiotracer injection because the distribution of ^{99m}Tc -labeled radiotracers remains relatively fixed for as long as 2 hours (Fig 12).** Alternatively, motion

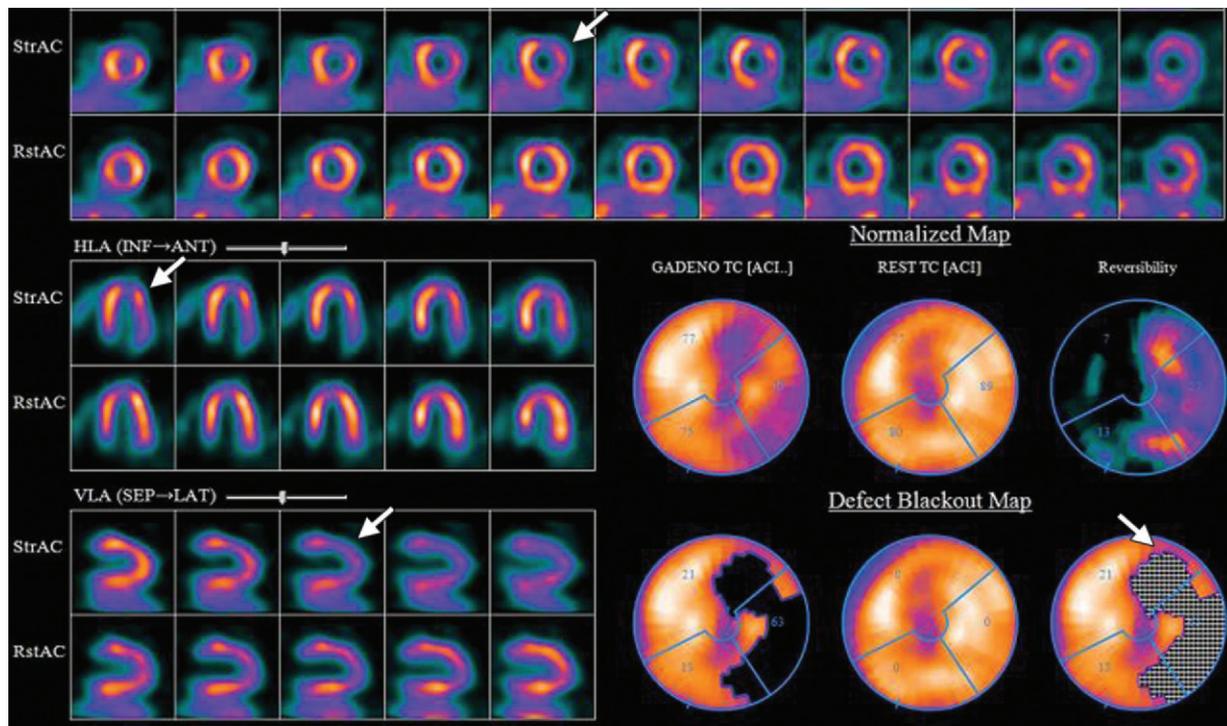
correction software is available that may be useful for eliminating misregistration due to slight or moderate motion. As with any imaging study, it is paramount that the technologist performing the examination make the patient as comfortable as possible and instruct the patient so as to prevent motion-related artifacts.

Artifacts of Misregistration

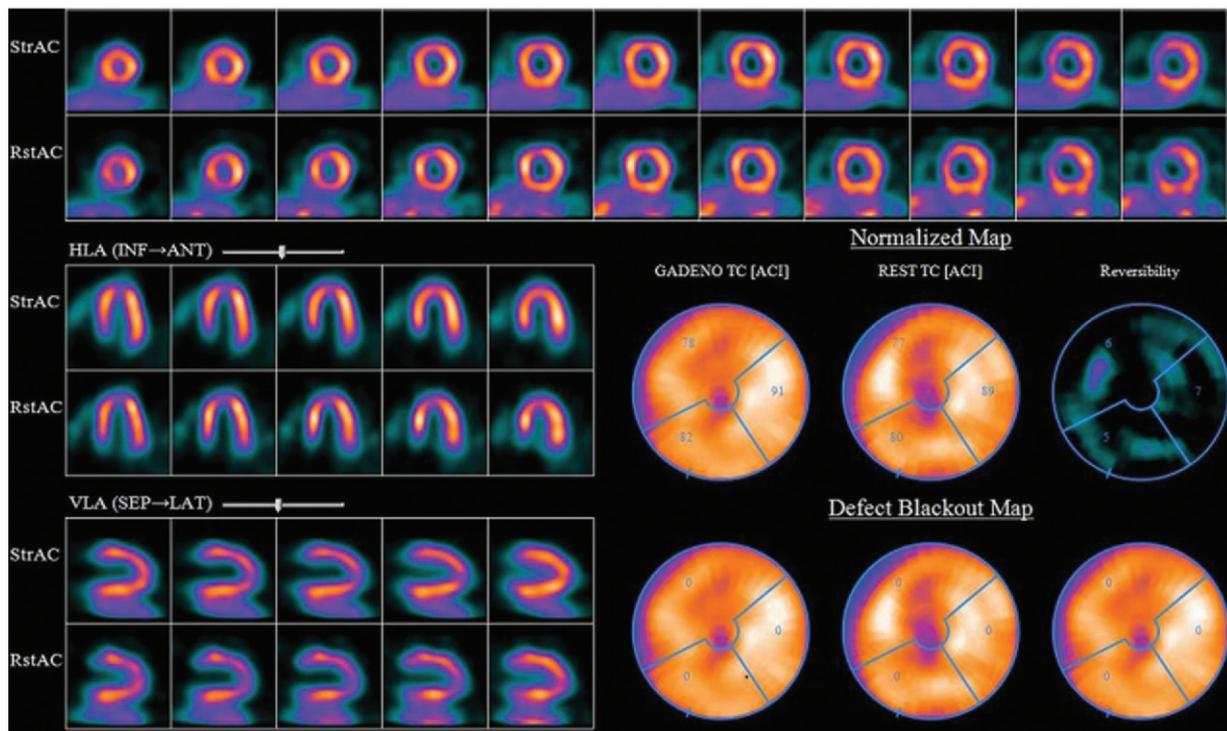
With current SPECT/CT systems, the low-dose CT data obtained for attenuation correction and the SPECT image data are acquired sequentially, and patient movement may occur between the two types of acquisitions. Although most new SPECT/CT systems include software to align the SPECT and CT datasets, misregistration may occur if care is not taken in the acquisition and processing of the datasets and may lead to new and unexpected kinds of artifacts. The results of SPECT/CT studies in phantoms and human subjects have shown that even a registration error of as little as 7 mm can lead to a substantial degradation in the quality of attenuation-corrected images (23). Such findings emphasize the importance of a careful review of the CT attenuation map and verification of its accurate coregistration with the SPECT images (Fig 13). **The goal of image coregistration is to precisely superimpose, in all three dimensions, the cardiac radiotracer activity data from the SPECT scan and the cardiac attenuation data from the CT scan.** Inadvertent superimposition of myocardial radiotracer activity on the lung can produce artifacts simulating large and severe perfusion defects, most commonly in the lateral wall (24).

Teaching
Point

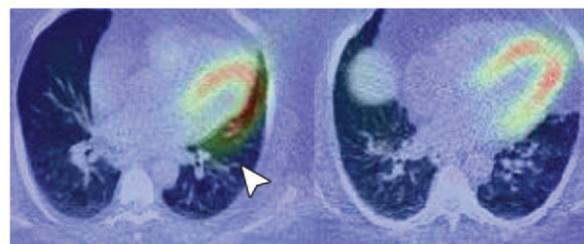
Teaching
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a.



b.



c.

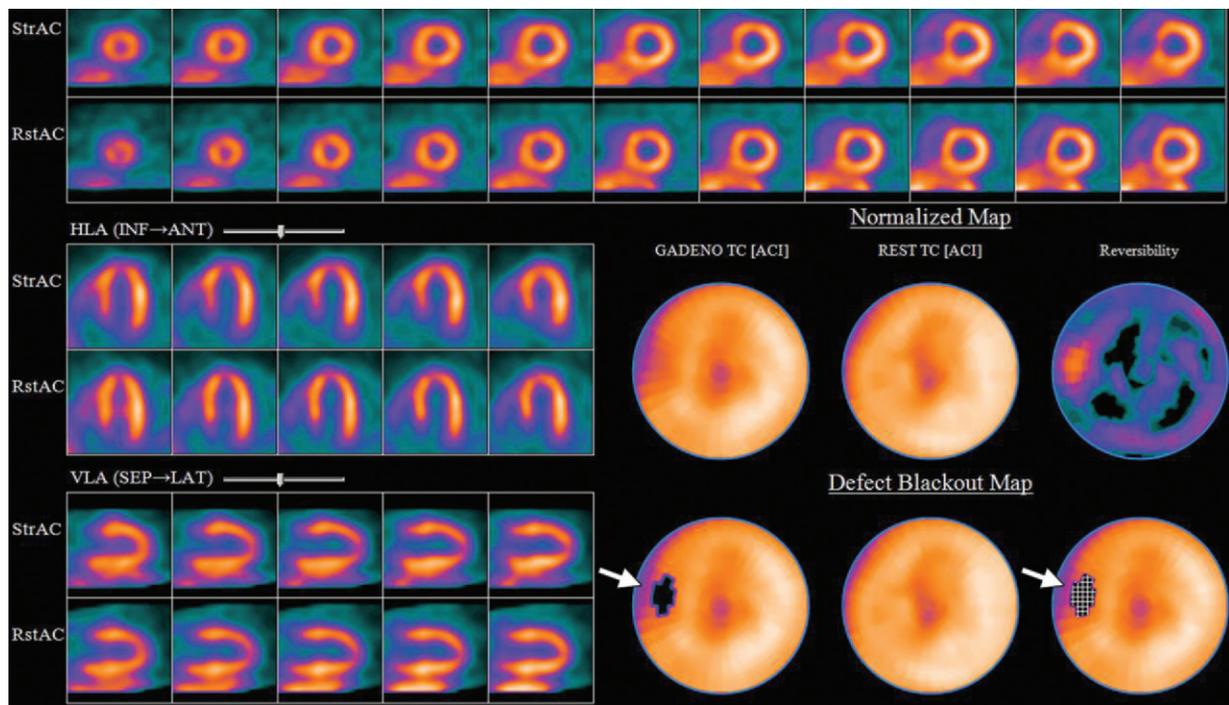


Figure 14. Summary screen from an attenuation-corrected stress (*StrAC*)-rest (*RstAC*) myocardial perfusion imaging examination performed with SPECT/CT in a patient with a left bundle branch block. Defect blackout maps from stress imaging show a small reversible perfusion defect in the midseptum (arrows), but this region appears normal on the rest images, and the septum is an unusual location for isolated coronary artery disease. Septal perfusion defects, whether reversible or fixed, are most likely to represent left bundle branch block–related artifacts. *ACI* = attenuation-corrected images, *GADENO TC* = ECG-gated stress imaging with regadenoson and a ^{99m}Tc-labeled tracer, *HLA (INF → ANT)* = horizontal long axis (inferior to anterior), *REST TC* = rest imaging with a ^{99m}Tc-labeled tracer, *VLA (SEP → LAT)* = vertical long axis (septum to lateral wall).

Artifacts of Left Bundle Branch Block

Patients with a left bundle branch block who undergo perfusion imaging during exercise- or dobutamine-induced stress (which is associated with a significantly increased heart rate in comparison with the resting heart rate) may appear to have a reversible or fixed septal perfusion defect (25). The exact etiology of these apparent septal defects is uncertain; however, the decrease in septal blood flow that is seen at higher heart rates may be related to asynchronous septal contraction resulting directly from the perturbed activation sequence in patients with left bundle branch block and from incomplete relaxation of the septum during diastole. Diastole is the only phase of the cardiac cycle in

which left ventricular myocardial perfusion occurs; and when the heart rate increases, it does so primarily because of a shortening of diastole, with little effect on the duration of systole. As a result of the conduction delay inherent in left bundle branch block, the relatively limited time for septal myocardial blood flow is accentuated by the increased heart rate during exercise- or dobutamine-induced stress. Thus, the apparent septal defect is often more pronounced when stress is induced by exercise or by dobutamine, which push the heart rate higher, than when stress is induced by vasodilators, which generally have a limited effect on heart rate (Fig 14)

Teaching Point

Figure 13. (a, b) Summary screens from an attenuation-corrected stress (*StrAC*)-rest (*RstAC*) myocardial perfusion imaging examination performed with SPECT/CT in a patient with chest pain. Initial screen shows a large reversible perfusion defect in the lateral and anterolateral wall (arrow in a), an artifact that is due to misregistration of the CT attenuation map and SPECT image dataset. Summary screen obtained after re-registration of the SPECT and CT datasets (b) shows normal perfusion at the site of the apparent perfusion defect in a. *ACI* = attenuation-corrected images, *GADENO TC* = ECG-gated stress imaging with regadenoson and a ^{99m}Tc-labeled tracer, *HLA (INF → ANT)* = horizontal long axis (inferior to anterior), *REST TC* = rest imaging with a ^{99m}Tc-labeled tracer, *VLA (SEP → LAT)* = vertical long axis (septum to lateral wall). (c) Fused SPECT/CT image obtained after the first postprocessing attempt (left) shows a defect in coregistration, with projection of the lateral wall of myocardium over the lung field (arrowhead). Fused image obtained after proper coregistration of the SPECT and CT datasets (right) shows normal perfusion.

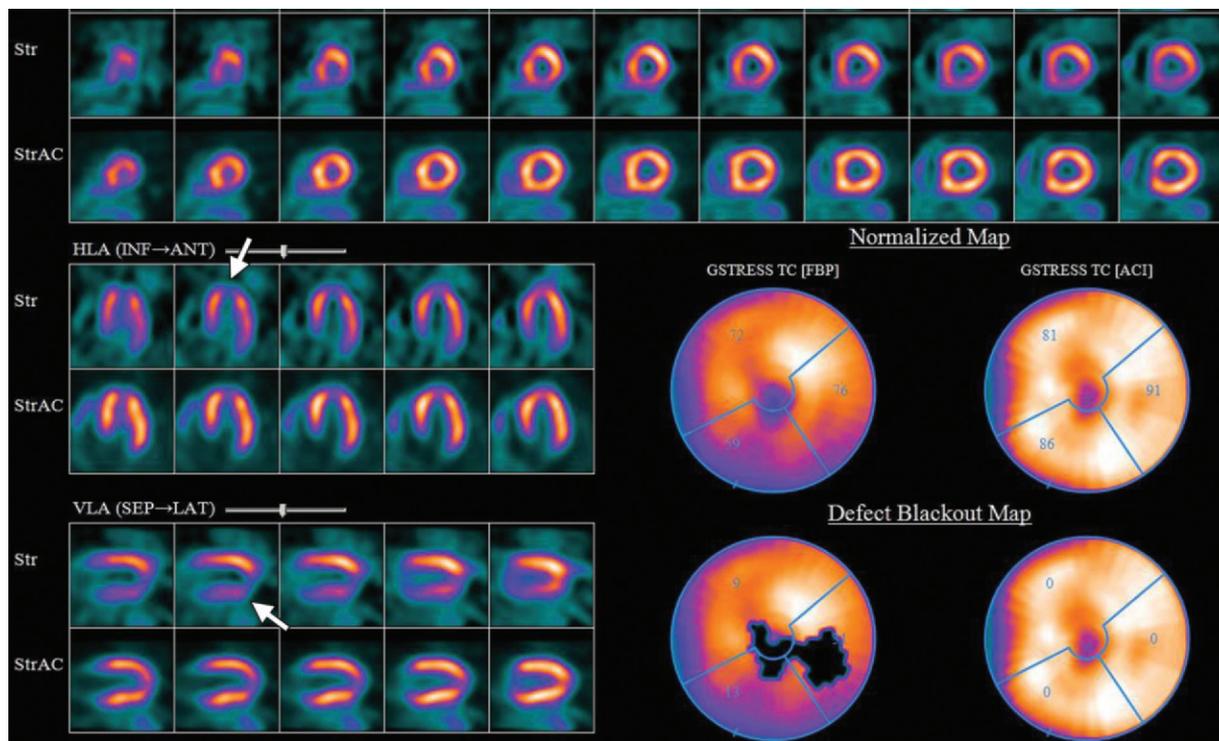


Figure 15. Summary screen from a stress-only myocardial perfusion imaging examination performed with SPECT/CT, with (*StrAC*) and without (*Str*) attenuation correction, shows an apparent small perfusion defect at the cardiac apex on both sets of images (arrows). This commonly observed feature is produced by apical thinning, and it should not be confused with a true perfusion defect; note that left ventricular wall motion and thickness appear normal. *ACI* = attenuation-corrected images, *FBP* = filtered back projection images, *GSTRESS TC* = ECG-gated stress imaging with a ^{99m}Tc -labeled tracer, *HLA (INF → ANT)* = horizontal long axis (inferior to anterior), *VLA (SEP → LAT)* = vertical long axis (septum to lateral wall).

(26). In addition to the appearance of a septal perfusion defect, ECG-gated SPECT studies often demonstrate asynchronous, hypokinetic, or paradoxical septal wall motion. However, while septal motion may be abnormal, normal septal wall thickness is often preserved in the presence of left bundle branch block. A left bundle branch block-induced perfusion defect typically spares the apex and anterior wall segments. Any involvement of these regions is suggestive of the presence of concomitant obstructive stenosis of the left anterior descending coronary artery.

Effects of Normal Apical Thinning

Apical thinning is a normal anatomic finding and is commonly seen. The etiology of this finding is multifactorial. In some people, thinning may be more prominent than usual and may simulate a perfusion defect. Apical thinning is more apparent on attenuation-corrected images and may be accentuated by the scatter correction and resolution recovery processes that are commonly incorporated in the reconstruction of attenuation-corrected images. In addition, because the apex

is closest to the detector, the spatial resolution of the normally thin apical segments of the left ventricle is greater than that of other segments. Apparent perfusion defects resulting from apical thinning are best seen on vertical and horizontal long-axis cardiac images and polar map displays (Fig 15). ECG-gated stress and rest SPECT images in such cases will show normal wall motion and normal wall thickening. With matching stress and rest perfusion patterns, recognition of preserved wall function confirms that the apparent perfusion defect is prominent apical thinning and not infarcted myocardium.

Conclusions

Accurate interpretation of SPECT/CT myocardial perfusion imaging studies requires both a working knowledge of potential abnormalities and a thorough understanding of the artifacts that can occur in image data acquisition and processing. Factors such as patient motion and improper alignment of the raw SPECT and CT image datasets can lead to propagation of artifacts on the final images. The attenuation-corrected images can often help eliminate defects produced by soft tissue attenuation. However, attenuation

correction itself may introduce artifacts if the anatomic and scintigraphic images are misregistered in the process. The type of stress study performed also may affect the outcome, because left bundle branch block–related artifacts are accentuated by physical stress and minimized by pharmacologic stress. Review of the raw SPECT and CT images as well as the final reconstructed images can help prevent misdiagnoses due to artifacts.

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Interpretation of SPECT/CT Myocardial Perfusion Images: Common Artifacts and Quality Control Techniques

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ECG-gated stress images are often helpful for differentiating between the two: An area of infarction exhibits abnormal wall motion and wall thickening, whereas an attenuation artifact shows normal wall motion and normal wall thickness.

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When a perfusion defect is identified, its location, size, severity, and reversibility must be reported.

Page 2053 (Figure on page 2052)

If a substantial amount of motion is detected during a study with a ^{99m}Tc -labeled radiotracer, repeat imaging can be performed without a second radiotracer injection because the distribution of ^{99m}Tc -labeled radiotracers remains relatively fixed for as long as 2 hours (Fig 12).

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Page 2055

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