Artifacts and Pitfalls in Myocardial Perfusion Imaging*

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Myocardial perfusion imaging (MPI) is an important imaging modality in the management of patients with cardiovascular disease. MPI plays a key role in diagnosing cardiovascular disease, establishing prognosis, assessing the effectiveness of therapy, and evaluating viability. However, MPI is a complex process, subject to a variety of artifacts and pitfalls, which may limit its clinical utility. These factors may be related to the patient (including unique aspects of the patient's heart), the nuclear medicine equipment, or the actions of the technologist. After reviewing this article, the reader should be familiar with the causes and the effects of these potential artifacts and pitfalls. The reader should develop an understanding of steps to limit these factors, actions to correct them if they do arise and, when necessary, how to incorporate their influence into the interpretation of the study.

Key Words: myocardial perfusion imaging; artifacts; cardiac imaging; SPECT

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Cardiovascular disease is the number one cause of death in North America. It also presents an enormous societal burden with respect to morbidity, health care expense, and personal hardship. Myocardial perfusion imaging (MPI) is a valuable tool in the management of patients with cardiovascular disease. With its unique ability to evaluate perfusion at the cellular level and to assess perfusion at peak exercise stress, MPI plays an important role in diagnosing cardiovascular disease, establishing prognosis, assessing the effectiveness of therapy, and evaluating viability. The clinical importance of MPI is in part reflected in its use, with annual double-digit growth (*1*).

Whereas MPI is a valuable diagnostic tool, it is also a complex physiologic imaging process, which exposes it to several potential pitfalls and artifacts that can limit the utility of the study. The overwhelming majority of MPI studies are now performed using SPECT and electrocardiographic (ECG) gating, which further add to the complexity of the study. Artifacts and pitfalls can arise at any stage in the MPI process and can be grouped into issues related to the patient, the equipment, or the technologist. As depicted in Figure 1, there is considerable overlap. For example, patient motion clearly originates with the patient, but the technologist has a role to recognize it and, where appropriate, to use the motion correction capabilities of the equipment to minimize its effect on the study. Some problems, such as motion and gating errors, are truly considered artifacts. These must be minimized in preparation for and during the study and, if necessary, recognized and corrected after the fact. The technologist plays a key role in these steps. Other problems, including cardiac abnormalities such as balanced ischemia and hypertrophic cardiomyopathy, are more properly classified as interpretation pitfalls. These aspects do not arise from any limitation of the procedure itself. Interpreting physicians must be familiar with these to ensure a proper evaluation of the study.

This article will review the preimaging, technical, patient-related, and heart-related artifacts and pitfalls that may compromise the performance and interpretation of MPI studies. It is essential to be aware of these factors, to limit them wherever possible, and to recognize them when they do arise in clinical situations.

PREIMAGING ISSUES

Patient Preparation

The first step in ensuring an optimal study is patient preparation. To limit gut activity adjacent to the heart, patients should have nothing by mouth or have only a light meal, depending on the institution's preference. Patients should wear comfortable clothing and footwear for the exercise stress portion of the examination. If the study is being done for the primary diagnosis of coronary artery disease, then sensitivity will be maximized if certain cardiac medications are withheld (*2*), though this should be done only if approved by the referring physician.

If a pharmacologic stress test with a vasodilator such as adenosine or dipyridamole is to be performed, the patient

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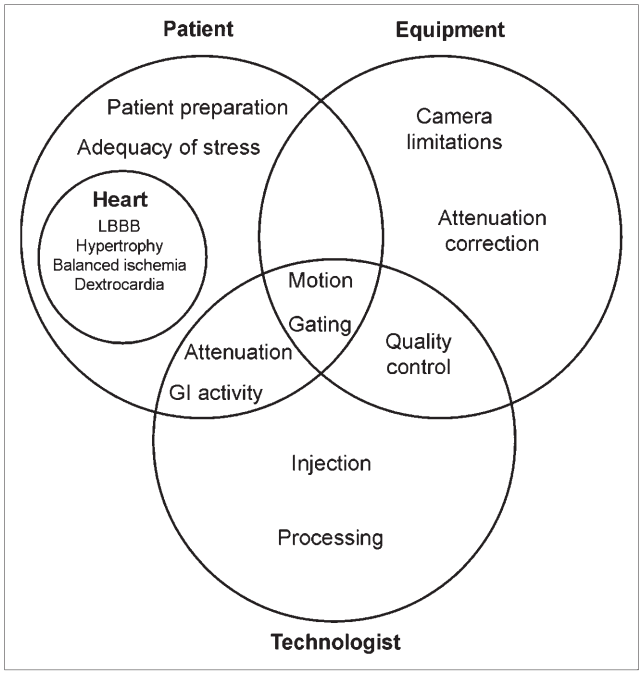

FIGURE 1. Causes of, and potential corrections for, MPI artifacts and pitfalls may be related to the patient, the equipment, or the technologist, often with overlap among these categories. LBBB = left bundle branch block; GI = gastrointestinal.

should abstain from medications containing methylxanthines and beverages, food (such as chocolate), and medications containing caffeine for 12 h (*2*) to 24 h (*3,4*). Caffeine and methylxanthines block the adenosine receptors on arterial smooth muscle cells, thus limiting the effectiveness of these vasodilator agents (*4*). Many institutions require that caffeine be avoided even if an exercise stress is planned, in case there is a need to switch to a pharmacologic stress. Note that some decaffeinated coffee contains up to 13 mg of caffeine per 240-mL (8-oz) serving, so it may be best to have the patient avoid alleged decaffeinated beverages as well (*4*).

Before imaging, metal and other potential attenuators must be removed from the patient if they will project into the imaging field of view and potentially interfere with the study. Figure 2 shows the raw data from a MPI study of a patient with a cardiac telemetry device on her chest, which projects over the heart during the SPECT acquisition, resulting in focal attenuation.

Cardiac Stressing

The test sensitivity for ischemia is optimized by having the patient perform the exercise portion of the test to a maximal safe level. This is generally taken to be 85% of the patient's age-predicted maximal heart rate (*3*). Of course, not all patients can safely reach this level, and the test may need to be stopped for other reasons, such as moderate-to-severe angina, significant blood pressure drop, sustained ventricular tachycardia, and others (*5*). If the stress test is

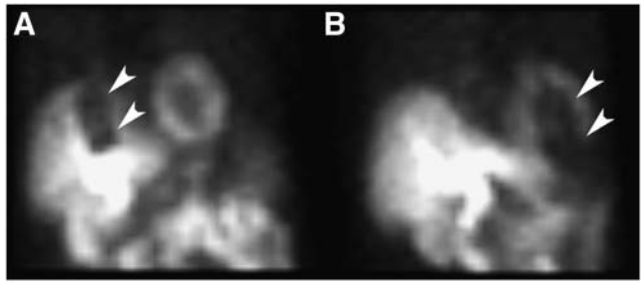

FIGURE 2. (A and B) Two different views from raw data of a MPI study reveal focal attenuation (arrowheads) from an unrecognized telemetry monitor on the patient's chest.

terminated before reaching the optimal level, the sensitivity for identifying ischemia will be reduced (*2*). It is also important to have the patient continue exercising at the maximal level for a minimum of 1–2 min after the injection of the radiopharmaceutical if they can safely do so. This allows for adequate circulation and uptake, ensuring that the distribution of radiopharmaceutical within the heart reflects the state of perfusion at maximal stress.

The sensitivity of pharmacologic stress is believed to be roughly equivalent to that of an exercise stress test in which the maximal 85% of age-predicted heart rate is reached, provided, of course, that caffeine is avoided.

Radiopharmaceutical Injection

Commonly used single-photon MPI radiopharmaceuticals include ^{99m}Tc-sestamibi, ^{99m}Tc-tetrofosmin, and ^{201}Tl. Dose recommendations for MPI are provided in the SNM guidelines (*2*). Doses may be adjusted according to patient weight depending on institutional practice.

The placement of an intravenous line is recommended for radiopharmaceutical injection for the rest and stress portions of MPI. The insertion of an intravenous line will reduce the possibility of an infiltrated dose. If there is any question with regard to an infiltrated dose, a static image of the injection site should be obtained. Figure 3A shows the raw data from a same-day rest–stress MPI study. A dose of 407 MBq of ^{99m}Tc-sestamibi was used for the rest study, and 1,295 MBq was used for the stress study. It was noticed that the stress study was noisier than usual for a patient of this size and, indeed, on the raw data images the signal-to-noise ratio was similar to that of the rest study. An infiltrated injection was suspected, and this was confirmed with a static image of the injection site (Fig. 3B). A repeat-stress study was performed on the next day, with a dose of 1,184 MBq. The raw data from this study are also shown in Figure 3A, with a much better signal-to-noise ratio than that on the study with the infiltrated injection. On the repeat-stress perfusion images, there was a defect in the anteroseptum, not present on the stress images associated with the infiltrated injection (Fig. 3C), as that study reflected primarily the perfusion from the earlier rest study.

An infiltrated injection may compromise the study in 3 ways. First, because less radiopharmaceutical is taken up

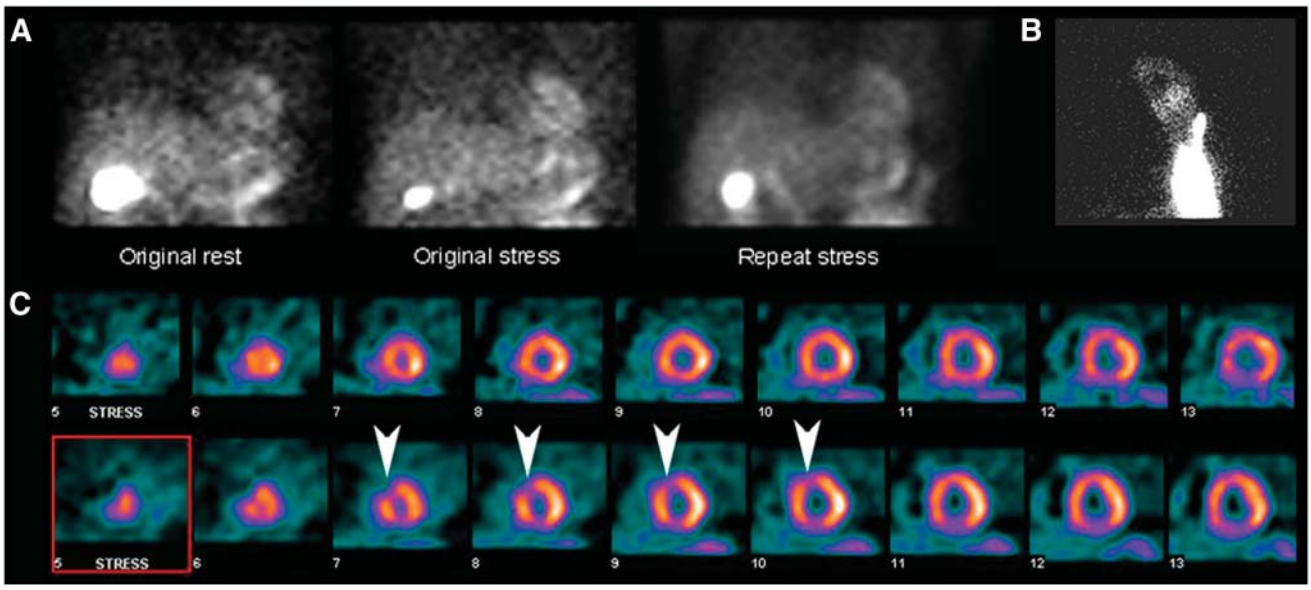

FIGURE 3. (A) Raw data images from same-day rest and stress images demonstrate low counts in stress image, similar to low-dose rest image, resulting from an infiltrated injection during stress study. Raw data from a repeat-stress study (right panel) on the following day demonstrate expected better counts from high-dose stress study. (B) Static image of injection site in right arm confirms infiltrated injection. (C) Short-axis views from infiltrated stress study (top row) and repeat-stress study (bottom row). Repeat-stress study demonstrates a stress-induced defect in anteroseptum (arrowheads) not present on the study with infiltrated injection.

by the myocardium, counting statistics are lowered, resulting in a poorer-quality study. Second, if the infiltrated injection occurs during the second phase of a same-day study, as in the case here, the resultant second scan will be predominated by activity from the first injection. Thus, ischemia induced during a stress study may be masked—a significant error. Third, an infiltrated injection can lead to altered distribution of the radiopharmaceutical, such as uptake in lymph nodes. As radiopharmaceuticals such as ^{99m}Tc-sestamibi, ^{99m}Tc-tetrofosmin, and ^{201}Tl can be taken up by tumors (*6,7*), visualization of lymph node activity on the cine raw data images resulting from an infiltrated injection may inappropriately lead to an investigation for malignancy. Figure 4A shows intense uptake in the right axilla on a MPI study performed with ^{99m}Tc-sestamibi. A static image of the injection site was later obtained (Fig. 4B) which revealed an infiltrated injection, and, hence, a workup for malignancy was avoided.

Another potential error related to the injection that can inappropriately result in an evaluation for malignancy is contamination. Figure 5A shows the MPI raw data from another study performed with ^{99m}Tc-sestamibi. There are 3 foci of activity projected over the chest, which could be mistaken for malignancy. However, the multiplicity of foci and the superficial location led to the suspicion that this was due to contamination. A separate image of the patient's shirt was obtained (Fig. 5B), confirming the presence of contamination. It is imperative when administering a radiopharmaceutical to beware of potential contamination. The intravenous line used should be wiped clean afterward and disposed of properly. A small drop of radiopharmaceutical may be easily spread from the intravenous line to the patient's clothing. If this is suspected, as in this case, the patient's clothing may be imaged separately to confirm contamination. It may then

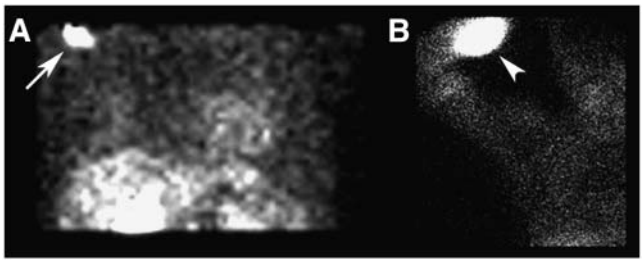

FIGURE 4. (A) Anterior frame from MPI raw data reveals a focus of intense uptake in the right axilla (arrow) that could be mistaken for metastatic lymph node involvement. (B) Static image of the injection site confirms an interstitial injection (arrowhead), which has resulted in lymphatic uptake of the radiopharmaceutical and deposition in axillary nodes.

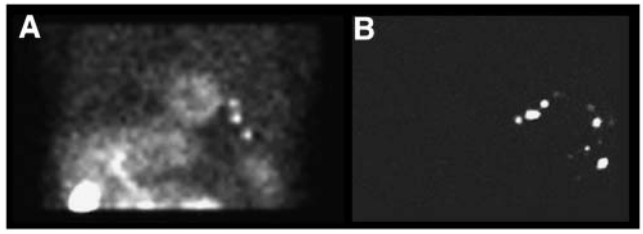

FIGURE 5. (A) Raw data frame demonstrates 3 foci of activity projecting over the thorax on the left, which could be mistaken for a neoplastic process. (B) Static image of the patient's shirt confirms contamination, responsible for the activity on raw data images.

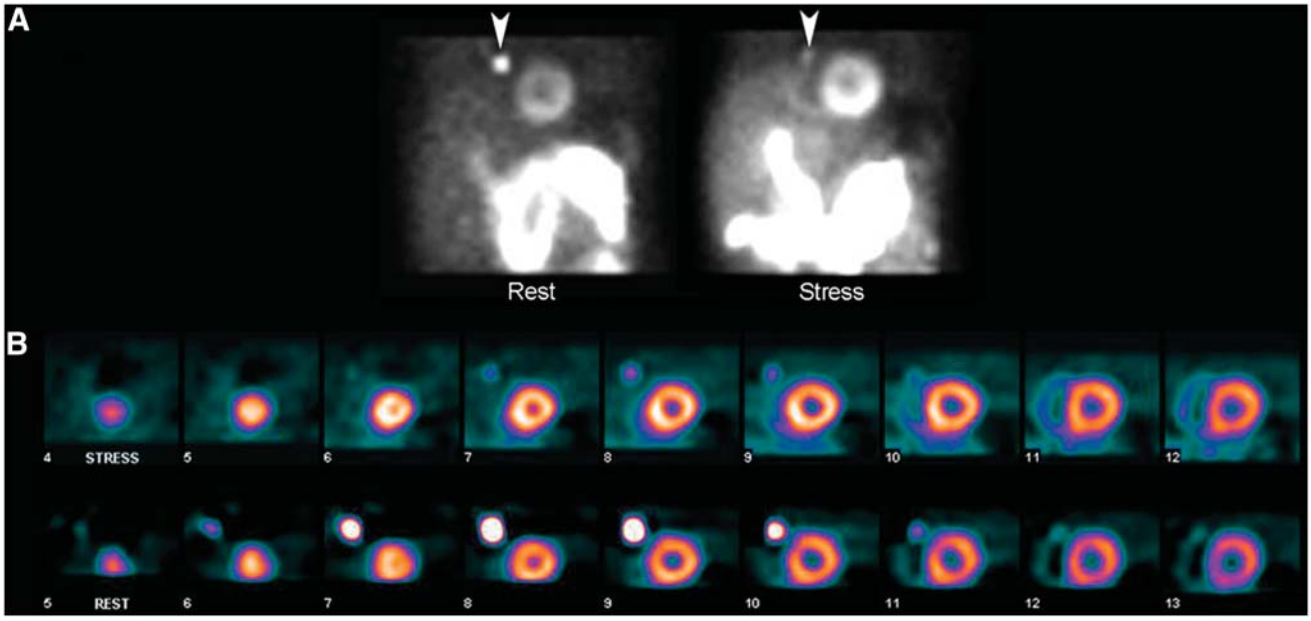

FIGURE 6. (A) Raw data images demonstrate a focus of uptake adjacent to the heart (arrowheads) resulting from retention of radiopharmaceutical within the patient's chest port, more intense on rest images. (B) Short-axis perfusion images reveal intense focal chest port activity, which could conceivably compromise evaluation of perfusion in adjacent LV.

become clinically necessary to repeat the study without the contamination if it is believed to compromise the reconstruction of the myocardial perfusion images.

A final issue related to the injection is the use of a port device that may act as a reservoir for the radiopharmaceutical. Similar to an infiltrated injection, this may result in lower counting statistics and a poorer-quality scan. Also, if the port is located close to the heart, the intense residual activity may interfere with the reconstruction, display, or interpretation of the myocardial perfusion images. Figure 6 shows intense activity in a chest port injection site close to the left ventricle (LV). This results in a very hot focus adjacent to the heart, which could compromise evaluation of perfusion, as will be discussed in the context of subdiaphragmatic activity. The retention of radiopharmaceutical in devices used for dose administration may be minimized by ensuring the device is adequately flushed with saline after radiopharmaceutical injection.

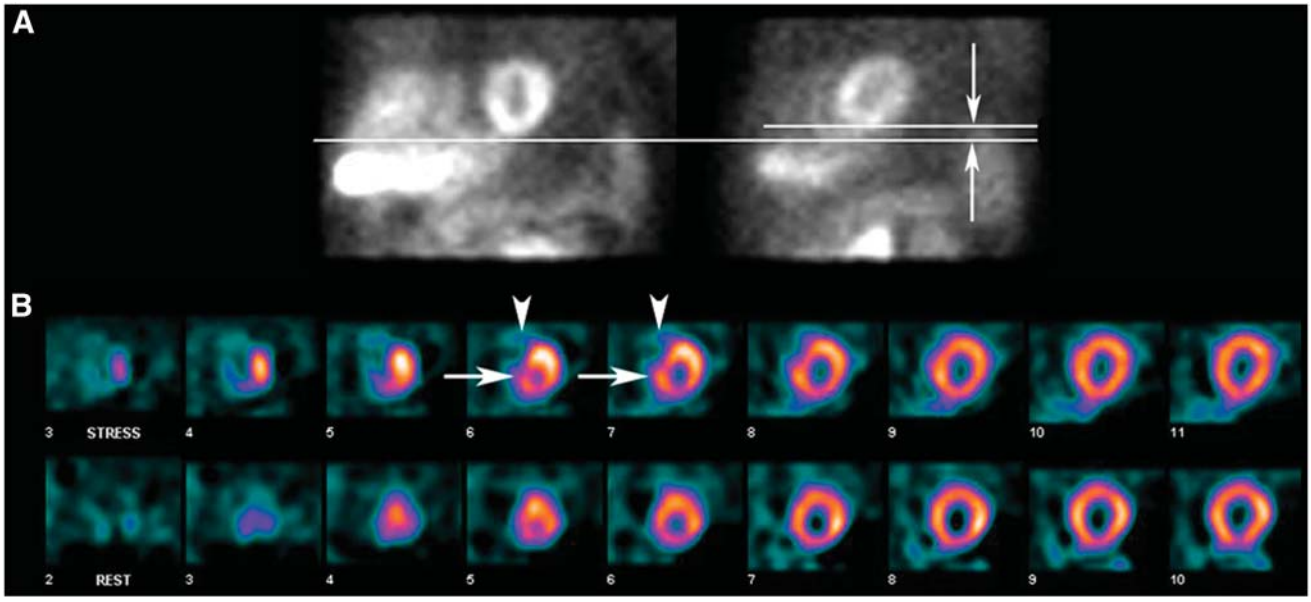

FIGURE 7. (A) Two frames from MPI raw data demonstrate offset of the LV between frames, indicative of patient motion. (B) Resultant perfusion images demonstrate a defect in apical septum and slight relative offset of lateral and septal aspects of the LV (arrows), along with a ''tail'' of activity extending from the LV (arrowheads), as a result of the patient motion.

TECHNICAL AND ACQUISITION ISSUES

Patient Motion

Patient motion is a common source of artifact on MPI studies. A number of motion parameters can influence the likelihood and magnitude of artifact formation. The greater the extent of movement, the greater is the likelihood of artifact. In a study evaluating ^{201}Tl scans (*8*), it was found that movement of 0.5 pixel (3.25 mm) did not cause a detectable defect, movement of 1 pixel could cause a detectable defect but this was rarely clinically significant, whereas movement of 2 or more pixels always caused a detectable artifact, and it was believed this could be clinically significant in 5% of cases. Movement in the axial direction was found to be of greater significance than movement in the lateral direction (*8*), although the opposite has also been found (*9*). Motion occurring in the middle of the acquisition is more significant than motion near the beginning or the end (*8*), whereas abrupt patient motion is more significant than gradual motion (*9*).

Figure 7 is the MPI study from a 58-y-old man being evaluated after a myocardial infarction. The raw data viewed in cine mode demonstrated significant patient motion, reflected in Figure 7A in 2 raw data frames. On the resultant myocardial perfusion images, there is an artifactual perfusion defect in the apical septum, with mild offset of the septal aspect of the LV relative to the lateral aspect on the short-axis views. There is also an artifactual "tail" of activity extending superiorly from the distal LV. This spectrum of findings has been deemed the "hurricane sign" because of its resemblance to the schematic depiction of a hurricane on weather maps (*10*). Similar findings can arise from center-of-rotation errors.

Cardiac creep is a form of gradual internal heart motion. Cardiac creep is most pronounced when postexercise images are acquired too soon (e.g., 5−10 min) after exercise. When a patient is exercising the lungs are expanded, which causes a shift downward of the patient's heart. When the patient is at rest, after the lungs are no longer expanded, the patient's heart then ascends to its normal location in the chest. This type of motion may be visualized during cine review of the raw SPECT data. Technologists should ensure that a postexercise acquisition is commenced 15−30 min after exercise (*2*); this will help avoid cardiac creep, in addition to lessening liver activity, as will be discussed. Cardiac creep is usually not a concern during rest imaging or pharmacologically induced stress imaging as imaging is recommended 45−60 min after radiopharmaceutical injection (*2*). Cardiac creep may be particularly relevant when using ^{201}Tl, as it is generally recommended to commence imaging within 5−10 min of injection so that imaging is performed before ^{201}Tl redistribution (*2*). Although cardiac creep is most highly associated with imaging shortly after exercise, it should be noted that it can also occur during rest imaging or delayed-stress imaging without any relation to exercise. Patients may experience anxiety and resultant deep breathing when first placed under the camera, which may subside throughout the image acquisition, resulting in the gradual upward movement of the heart.

Patient motion artifact can be reduced with a multihead camera system, as this decreases acquisition time and, hence, the likelihood of patient motion. However, it is possible for the effect on patient motion to be compounded relative to a single-head system, as a single episode of motion will be registered once on each camera head (*9*).

The technologist performing the study should ensure that the patient is relaxed and comfortable before the start of acquisition to limit the possibility of motion throughout the duration of the scan. Observation of the patient during the acquisition is also recommended to ensure that the patient remains still. Prone imaging may also be introduced to reduce patient motion (*11*).

In addition to taking steps before and during the acquisition to limit patient motion, the technologist must review the raw data in cine mode afterward to assess for motion. A decision must then be made as to whether additional steps are required. Minimal motion may be ignored, whereas more moderate motion should be corrected with the aid of the manufacturer's motion correction software. However, there are limitations to the degree of motion that can be corrected using software, and large amounts of motion will generally necessitate repeating the acquisition.

Gating Problems

Most MPI studies are performed with ECG gating. The advantages of gating are that it allows for the assessment of regional and global ventricular function and assists in discriminating certain artifactual defects from true perfusion abnormalities. During a gated acquisition, the cardiac cycle is divided into several individual time frames, and data are collected for each time frame summed over several heart beats. This is repeated for each projection angle of the gamma camera, over a range of 180° or 360°. An acquisition that acquires 8 frames per cycle for each projection

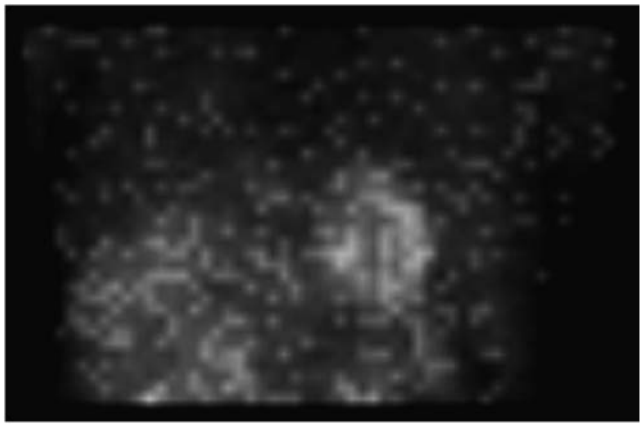

FIGURE 8. Raw data image demonstrates flickering artifact (numerous scattered bright pixels), indicative of a gating problem.

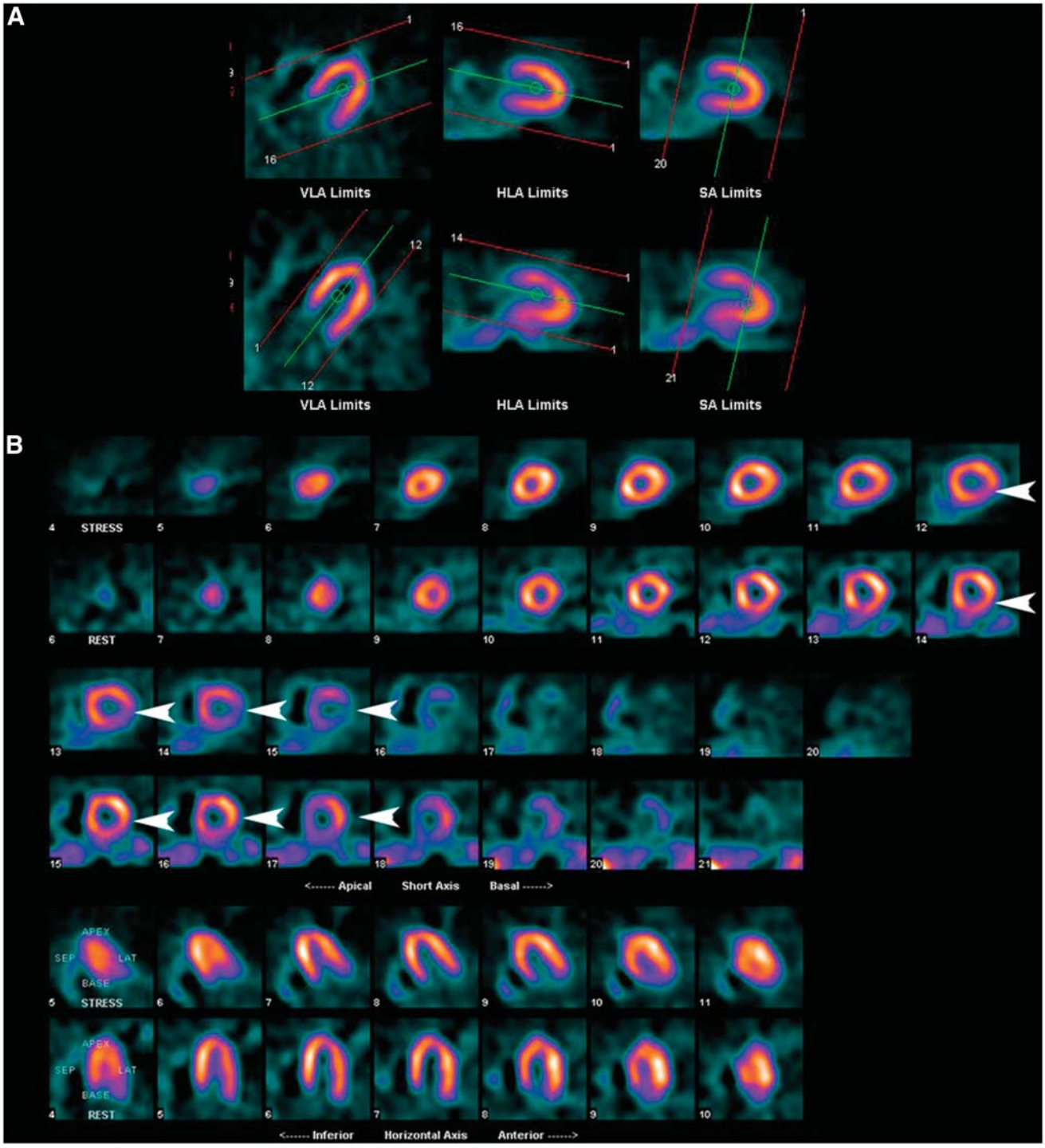

FIGURE 9. (A) Processing images demonstrate incorrect axis alignment in the horizontal long-axis (HLA) plane on the stress study. Proper alignment is present on the rest study. (B) Incorrect alignment results in an artifactual reversible defect in lateral wall on perfusion images (arrowheads). (C and D) Processing images (C) and perfusion images (D) from the same study, now with proper axis selection. Artifactual defect is no longer present. VLA = vertical long-axis; SA = short-axis.

angle is considered to produce reliable results in routine practice (*12*).

Obtaining accurate gating data from an ECG requires correct electrode placement and site preparation. Impedance, or the opposition to the current in an electrical circuit, may add noise to the ECG (*13*). Site preparation must be performed so that the least amount of impedance is present and optimal skin contact is obtained. Cleaning or shaving the skin, along with placement of electrode gel, will decrease impedance between the electrodes and the patient's

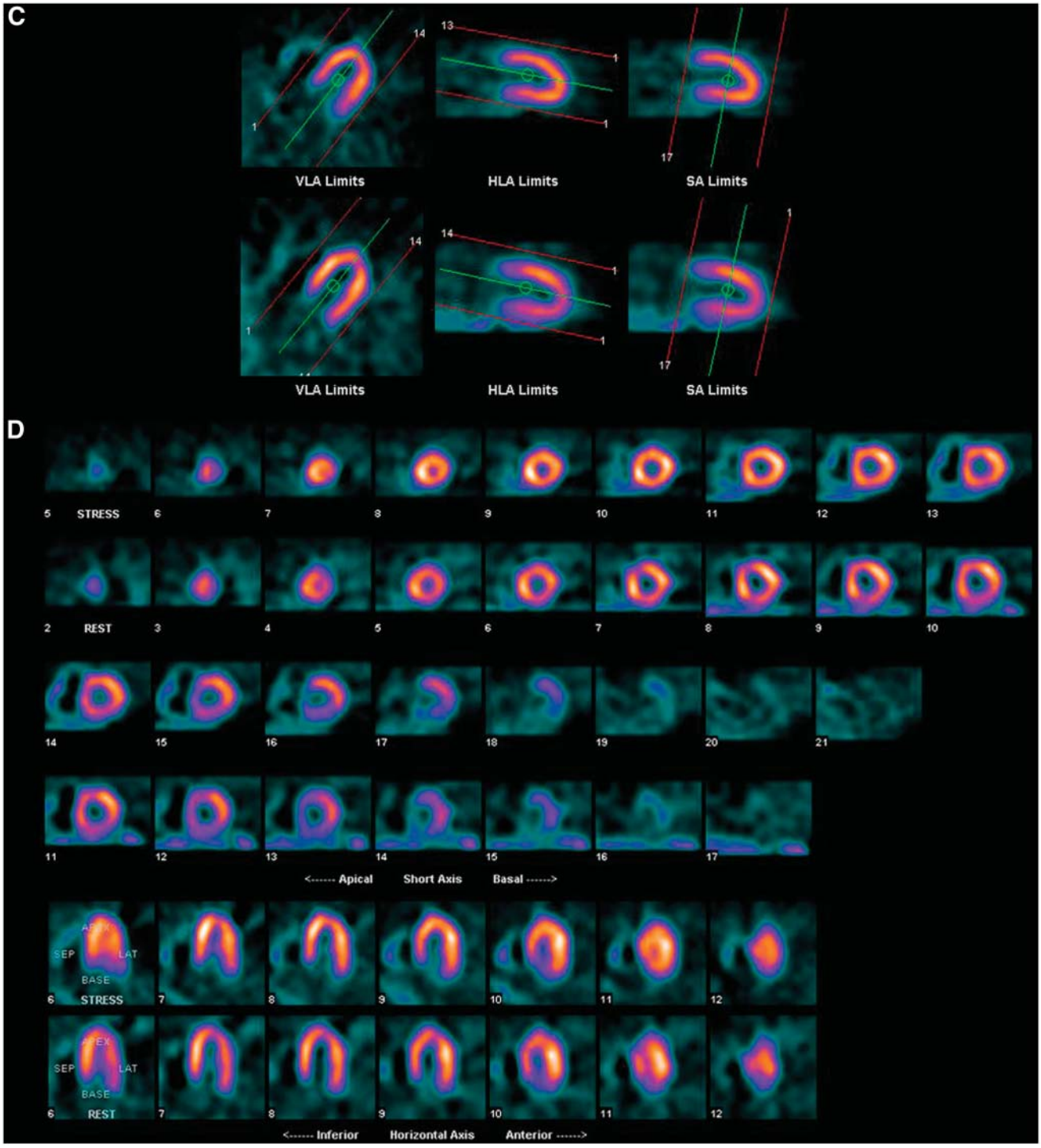

FIGURE 9. (Continued)

skin. The electrode wires should be securely connected to the gate box. Technologists should ensure that the patient is still and relaxed to obtain an optimal ECG signal.

Once the ECG has been established, the duration of the cardiac cycle, represented by the R–R interval, must be properly recognized by the camera system before beginning imaging. If changes in the length of the cardiac cycle occur during the acquisition, there may be frames in the cardiac cycle that do not have adequate counts. This can manifest as flickering artifact on the raw cine data (Fig. 8), which is an indicator of a potentially significant arrhythmia. The presence and severity of arrhythmias can be assessed using quality assurance screens plotting counts versus projection angle for the 8 time frames (*14*). Although it seems clear that arrhythmias may cause errors in assessment of wall motion, wall thickening, and ejection fraction (EF), less intuitively,

arrhythmias may also cause a significant error in assessment of perfusion defects (*14,15*). This arises from inconsistencies in the backprojection data due to rejection of beats not falling within the acceptance window. Different manufacturers have different methods for dealing with this, but if these are not available, a nongated study may need to be acquired in patients with severe arrhythmias to avoid perfusion artifacts (*14,15*). If the severe arrhythmia is known in advance, then the nongated study can be performed instead of the gated study, rather than as an additional acquisition.

Quality Control (QC)

A number of QC procedures are critical to provide optimal camera performance and, thus, ensure the diagnostic utility of myocardial perfusion studies. SPECT studies require additional QC testing and image correction beyond that required for routine planar imaging. The SPECT corrections that may cause the most significant negative effects on reconstructed data are center of rotation, multihead registration, and tomographic uniformity (*16*). Other useful SPECT QC testing may include pixel size calibration, tilt angle check, and SPECT phantom reconstruction (*17*). Where a transmission image is measured for the purpose of attenuation correction, testing of emission–transmission alignment should also be considered (*18*).

QC testing should be performed according to the guidelines and at the recommended frequency of the camera manufacturer and in accordance with the National Electrical Manufacturers Association (NEMA) recommendations for implementing SPECT instrumentation QC (*17*). A thorough review of SPECT QC testing has been previously provided in this journal (*16*) and will not be further elaborated on here.

Processing Errors

A number of technical errors may occur during the processing phase of MPI. The short-, horizontal long-, and vertical long-axis images are generated according to the limits and axis selection of the user. These should be chosen carefully to ensure that the entire myocardium is included and the axis angles are correct. Figures 9A and 9B demonstrate incorrect axis selection during data reconstruction. As demonstrated, this can lead to significant errors in the perfusion images. Whereas the error has been exaggerated here to highlight the point, small errors may be even more harmful, as they may introduce subtle errors in the perfusion images that may not be recognized as artifactual. For this same case, the correct axis selection is depicted in Figures 9C and 9D, resulting in no artifactual defect.

Software designed for processing MPI will typically normalize the myocardial activity to the hottest pixel. Therefore, when choosing the spatial limits for the production of myocardial slices, the goal is to select only myocardium and to eliminate extracardiac activity. However, it may be difficult and sometimes unavoidable to completely eliminate extracardiac activity if this would result in cropping some of the myocardium.

LVEF accuracy depends on the quality of the gate obtained during acquisition, as discussed previously, but may also be impacted during processing. Quantitative computer software searches for myocardial boundaries at end diastole and end systole and uses these to calculate the EF. If there is extracardiac activity close to the myocardium during acquisition, the computer software may falsely interpret this as myocardium. Therefore, the EF may be erroneously generated using bowel or liver uptake. Figure 10 illustrates the inability of the computer software to correctly identify myocardium due to stomach interference. The EF obtained is falsely calculated at 30%. After a repeat scan is performed and the stomach activity is cleared, the computer calculation is repeated and an accurate result of 56% is obtained. In cases where extracardiac interference occurs, it may be necessary to rescan the patient to obtain optimal results.

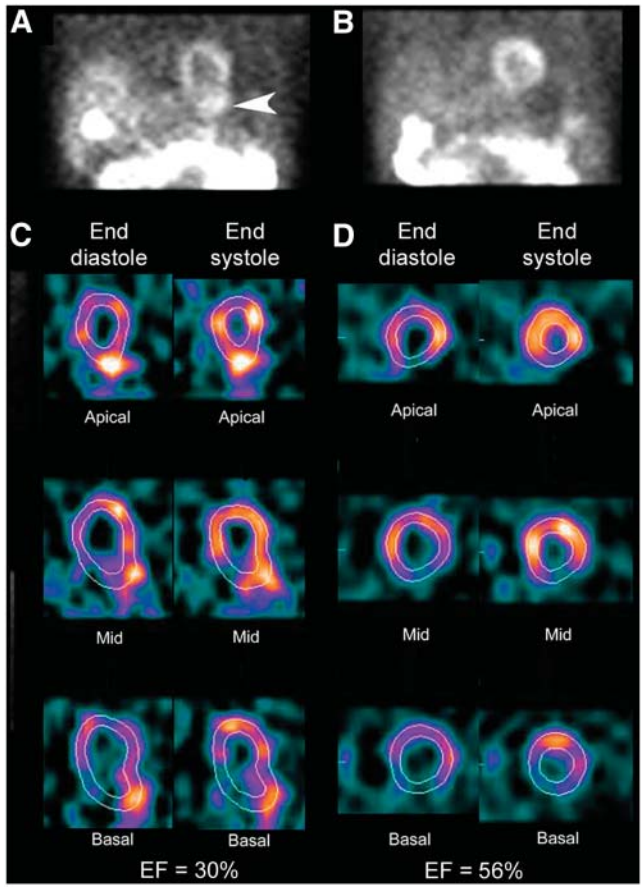

FIGURE 10. (A) Raw data frame from rest MPI study demonstrates prominent activity in stomach adjacent to LV inferior wall (arrowhead). (B) Raw data from delayed study after gastric activity had cleared. (C) Three short-axis views (apical, midventricle, and basal) during end diastole and end systole from gated study in A demonstrate the inability of the program to track LV wall motion as a result of intense gastric activity. This results in an erroneously low LVEF of 30%. (D) Corresponding views from gated study in B demonstrate proper tracking of LV wall motion and correct calculation of EF at 56%.

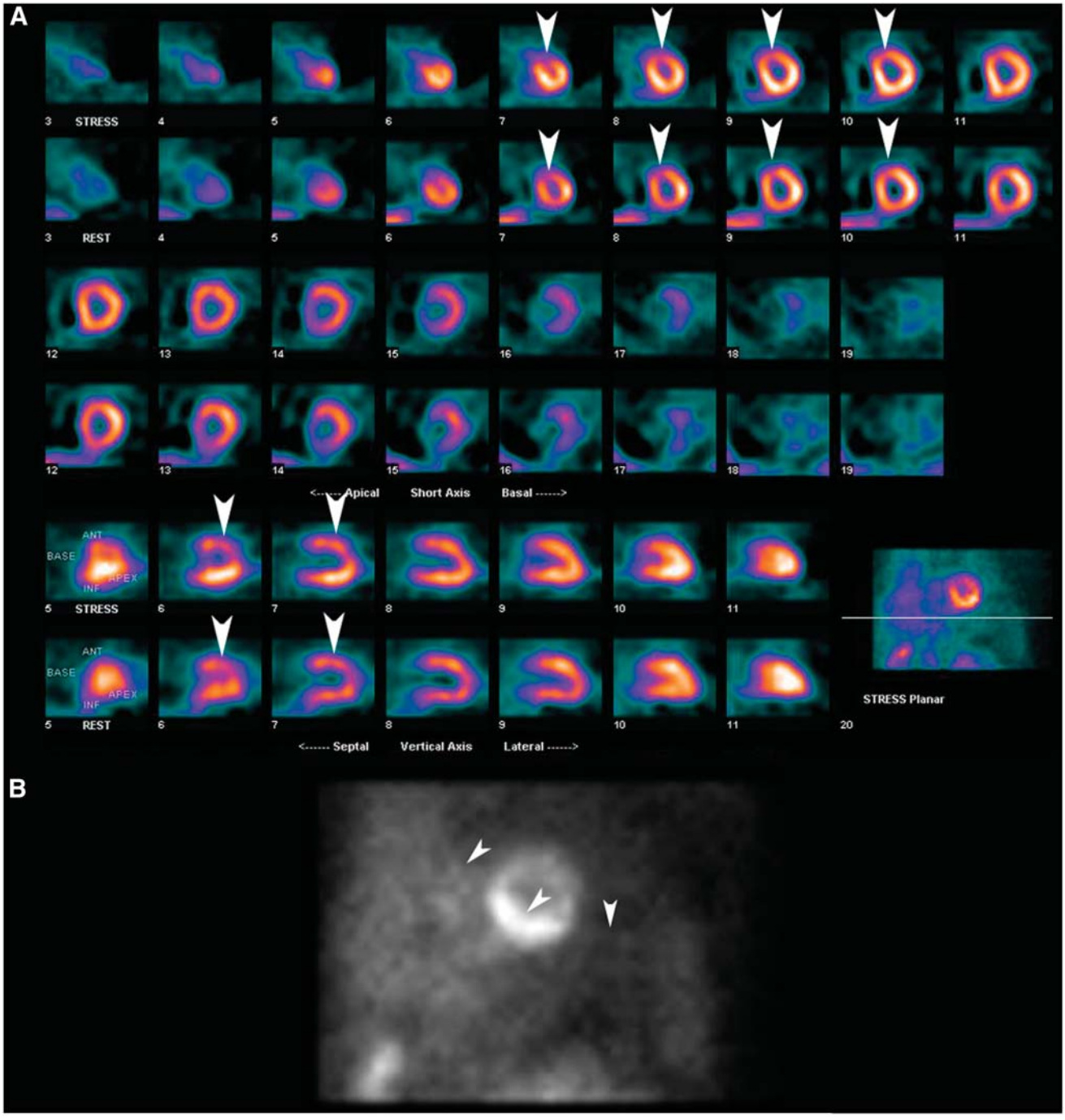

FIGURE 11. (A) Myocardial perfusion scan reveals a fixed defect in the anterior wall (arrowheads). (B) Frame from raw data demonstrates marked attenuation by left breast (arrowheads), which is causing the apparent perfusion defect.

This will be further discussed in the section on Subdiaphragmatic Activity.

Most software packages that are presently available to process myocardial perfusion images are user friendly and have a minimal number of steps required for complete processing. This aids in ensuring consistency and reproducibility among users.

Despite the best efforts of the technologist and the capabilities of the software, artifacts may still arise in response to processing-related issues. It is vital for the interpreting physician to view the raw SPECT cine images for potential sources of artifact before interpreting the reconstructed myocardial perfusion study.

PATIENT-RELATED ISSUES

Attenuation

Attenuation of photons by the patient's body is responsible for one of the most prevalent artifacts in MPI. A large body habitus results in generalized decreased counts,

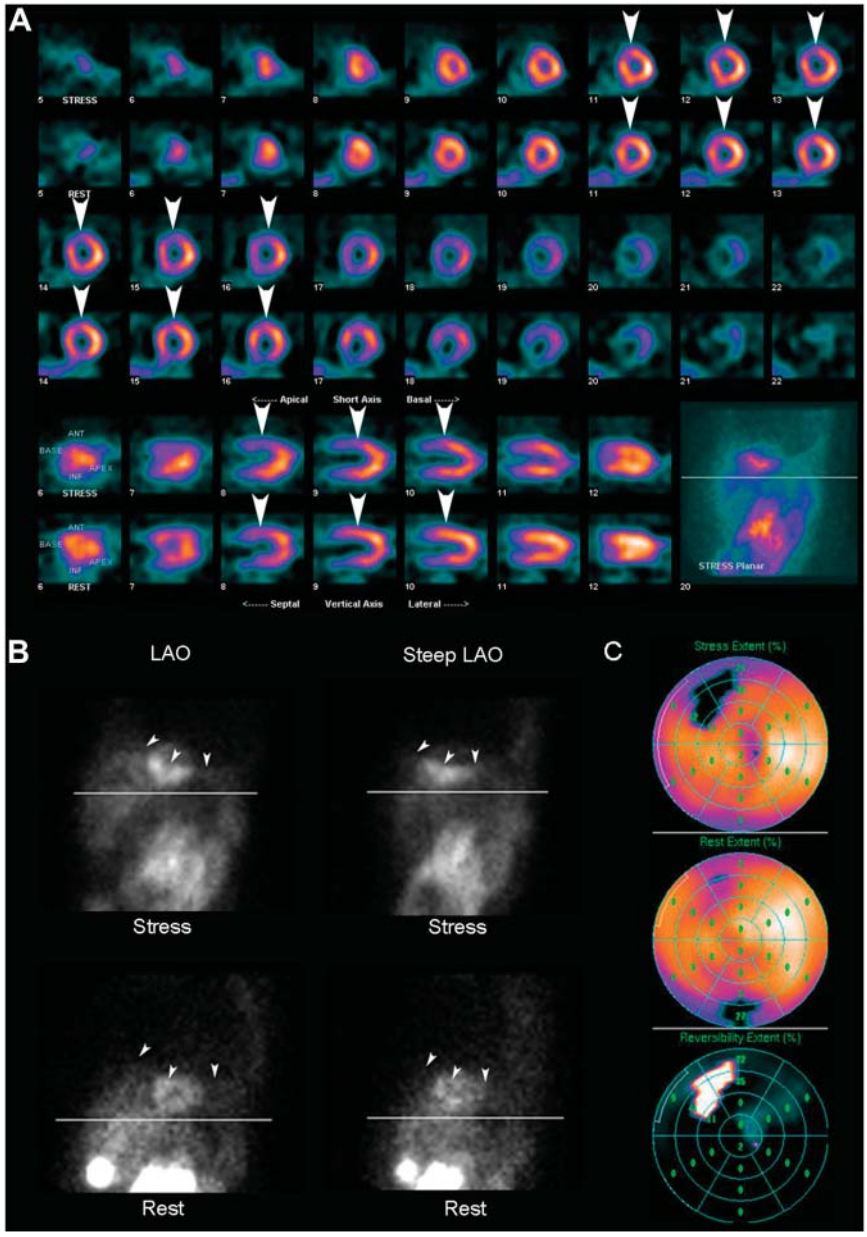

FIGURE 12. (A) Myocardial perfusion scan reveals a reversible defect in anterior wall (arrowheads). However, frames from raw data (B) indicate that left breast (arrowheads) was in a different position for the 2 acquisitions, possibly resulting in the apparent reversible defect. (C) Quantitative analysis reiterates apparent reversibility of the defect. LAO = left anterior oblique.

creating a noisier—and, therefore, less diagnostic—image. This can be mitigated by using a weight-based dosing regimen (*19*). Even more troublesome, however, is focal attenuation. Typically this is due to breasts in women and the diaphragm in men, although lateral chest wall fat can also lead to focal attenuation artifacts.

Breast attenuation usually results in a perfusion defect along the anterior wall of the LV, although, depending on body habitus, the lateral wall, septum, and even the apex can be affected. Figure 11A demonstrates a prominent defect in the anterior wall resulting from attenuation by large breasts in this 49-y-old woman being evaluated for chest pain. It sometimes can be difficult to distinguish breast attenuation artifact from a true defect. Clues to the artifactual nature of the abnormality include:

(a) The defect is fixed (unchanged between rest and stress imaging): This alone does not point to an artifactual origin, but a fixed defect along with normal motion and thickening on the gated study does favor breast attenuation.

(b) Appreciation of the size and density of the breasts: This can be evaluated by observing the raw data in cine format. Figure 11B is a frame from the stress raw data of the patient in Figure11A, demonstrating the marked heart attenuation by the left breast. Furthermore, it is important that the patient's body parameters, including bra size, be recorded on the patient's data sheet, along with whether there has been prior breast surgery, such as mastectomy or implants. If the patient has a breast prosthesis, it should be removed before imaging.

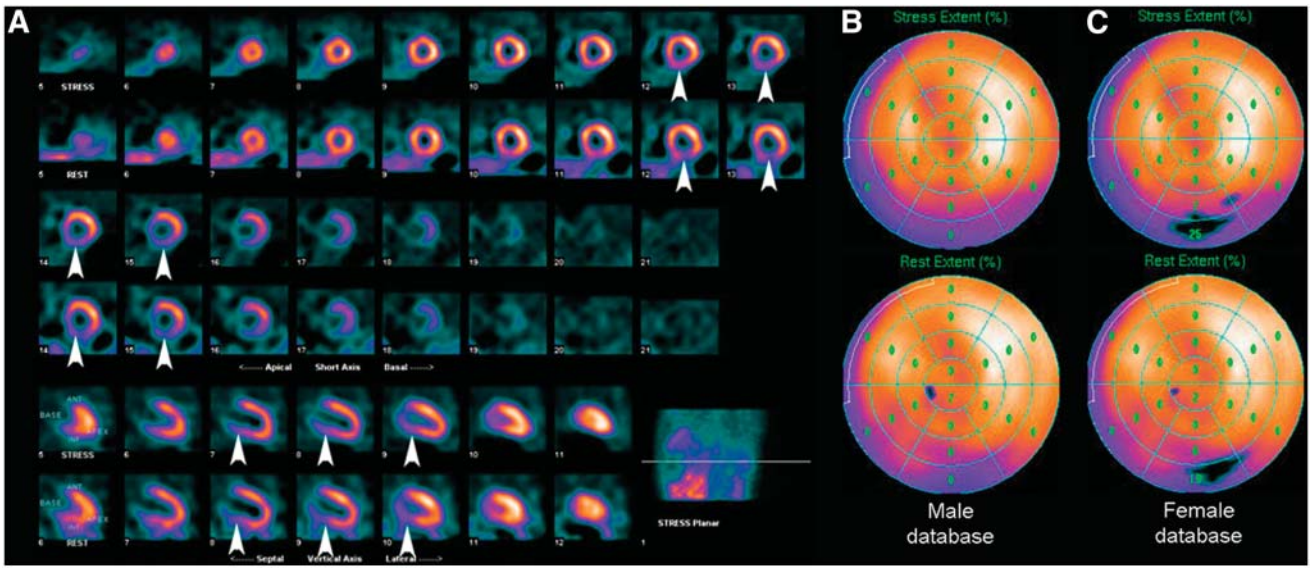

FIGURE 13. (A) Myocardial perfusion scan demonstrates typical mild fixed inferior wall perfusion abnormality (arrowheads) in male patient resulting from diaphragmatic attenuation. (B) Quantitative analysis using appropriate male database indicates no significant abnormality. (C) When incorrectly reprocessed comparing with female normal database, this male patient appears to have a significant fixed defect in inferior wall, as indicated by the blackout areas.

(c) The defect may not conform to an expected coronary artery distribution.

Whereas breast attenuation usually results in a fixed defect, occasionally, with large breasts, the breast may be in a different position on the rest and stress images, resulting in a reversible defect. Although rare, this presents a difficult diagnostic dilemma. Figure 12A demonstrates a reversible defect in the anterior wall, typical of ischemia, in this 49-y-old woman. However, frames from the raw data (Fig. 12B) reveal the left breast to be in a different position between the 2 studies, with more of the heart covered by the breast on the stress images than on the rest images, which may be resulting in the apparent reversible defect. Figure 12C shows the quantitative analysis, highlighting the difference between the rest and stress scans, and the potential false interpretation of anterior wall ischemia. It is important that the patient be positioned identically for the rest and stress imaging.

Large abdomens result in attenuation of the inferior wall. This is more commonly seen in men, resulting in sex differences in typical myocardial perfusion patterns, with men often having a mild artifactual defect in the inferior wall, as shown in Figure 13A in a 60-y-old man, versus the anterior wall defect in women (contrast Figs. 11A and 13A). This is considered in quantitative programs that compare patient scans with normal databases, with both male and female normal databases being required. When the perfusion study in Figure 13A is appropriately analyzed using the male normal database, there are no significant defects (Fig. 13B). However, when the study is reanalyzed using the female database, the program incorrectly identifies a fixed defect in

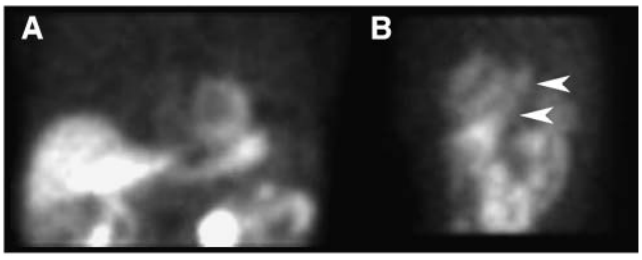

FIGURE 14. (A) Anterior raw data frame from a ^{99m}Tc-sestamibi study demonstrates activity in various subdiaphragmatic organs that can interfere with evaluation of perfusion of inferior wall. (B) Left anterior oblique raw data frame from patient with hiatal hernia and prominent gastric uptake (arrowheads), which can interfere with evaluation of lateral wall.

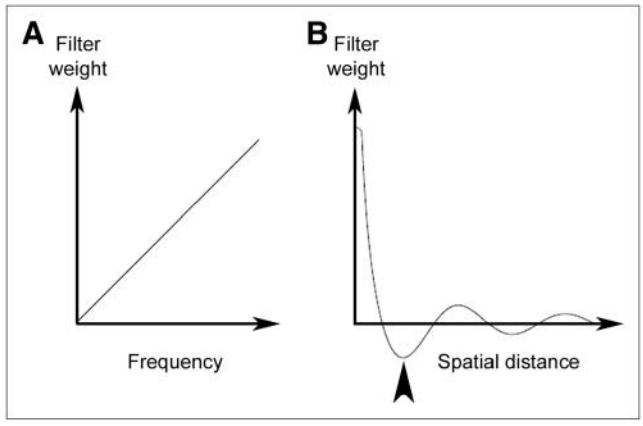

FIGURE 15. Ramp filter weighting factor in frequency domain (A) and spatial domain (B). Note negative side lobes (arrowhead) in spatial domain, which result in reduction in activity adjacent to a hot object, such as liver.

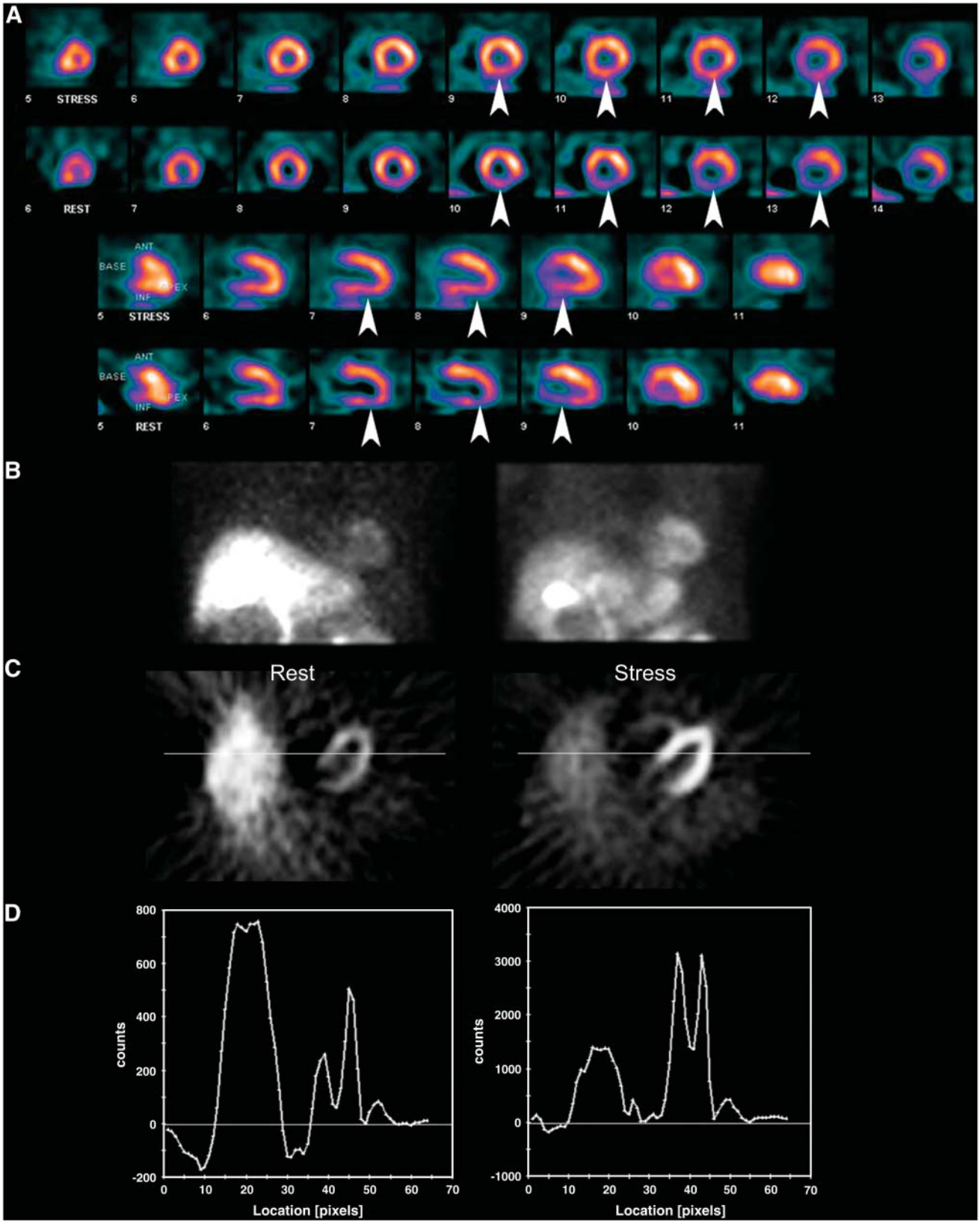

FIGURE 16. (A) Perfusion images demonstrate apparent perfusion defect in inferior wall that is much worse at rest than during stress (arrowheads). (B) Anterior frames from raw data reveal liver activity to be much greater than cardiac activity at rest (left frame), which is not the case on the stress study (right frame). (C and D) Transaxial slices at level of liver and heart (C) and count profiles across the images (D) (left frames rest, right frames stress). Note negative counts adjacent to intense liver activity on rest study, which results in artifactual reduction in counts in adjacent myocardium.

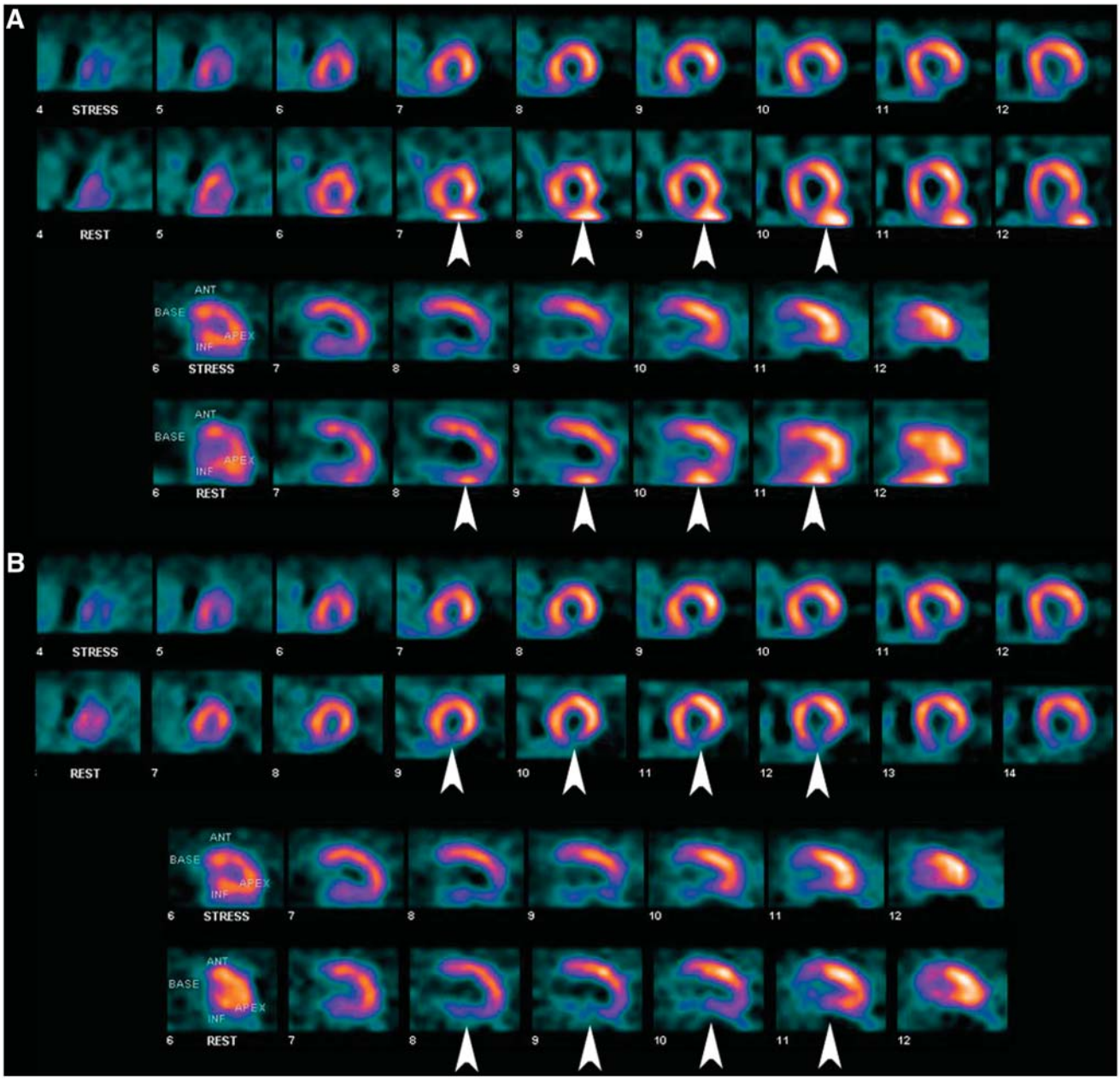

FIGURE 17. (A) Prominent liver activity adjacent to inferior wall defect on rest images renders it impossible to tell if there is any reversibility present. (B) Rest study was repeated with longer delay between injection and imaging, resulting in no confounding liver activity and, thus, a diagnostic scan. The same stress study is presented in both scenarios.

the inferior wall (Fig. 13C), indicated by the blackout area. Although the wrong sex database has been used here to illustrate a point, it has been suggested that it is occasionally appropriate to do so—for example, in a female patient who has had a left mastectomy. The effects of diaphragmatic attenuation may be lessened by imaging the patient in the prone position. However, prone imaging may introduce an anteroseptal attenuation defect. Thus, if prone imaging is to be performed, it should be done in addition to supine imaging, not as a replacement for supine imaging (*19*).

When performing MPI with ^{201}Tl, attenuation is an even greater problem because of the lower counting rates and the lower emission energy relative to ^{99m}Tc. The attenuation coefficient for ^{201}Tl is approximately 19% greater than that of ^{99m}Tc. For 10 cm of soft-tissue attenuation, this results in approximately 30% more ^{99m}Tc photons exiting the body for detection than ^{201}Tl photons.

Various attenuation-correction techniques are available (*20,21*). These are becoming more widely accepted (*22*) and, when available, can significantly reduce the effect of attenuation. These techniques have traditionally used a rotating radioisotope source to generate transmission data that are used to perform the attenuation correction. More recently, combined modality SPECT/CT has been used, with

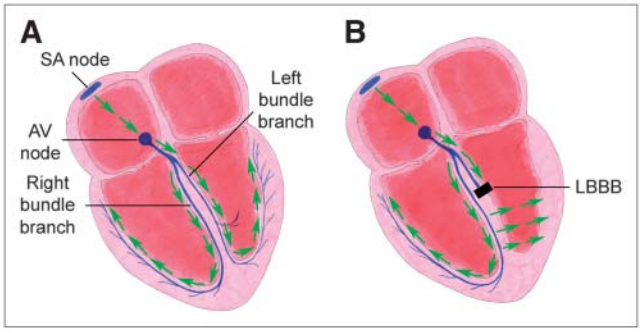

FIGURE 18. (A) Normal heart conduction system. (B) Heart conduction system in LBBB. Block results in delay in conduction to LV, as signal has to take a circuitous route via the right ventricle. SA = sinoatrial; AV = atrioventricular.

the CT x-rays being used to generate the transmission data. Even more accurate attenuation correction is available when performing myocardial perfusion studies with PET.

Subdiaphragmatic Activity

Prominent activity is frequently present in subdiaphragmatic organs adjacent to the heart. Activity is present in the liver and bowel as a result of hepatobiliary excretion of the radiopharmaceutical and can be present in the stomach due to reflux of radiopharmaceutical into the gastric lumen from the duodenum or because of uptake of free ^{99m}Tc-pertechnetate by the gastric mucosa. Typically this activity interferes with evaluation of the adjacent inferior wall (Fig. 14A) but rarely, in the setting of a hiatal hernia, the lateral wall can be affected (Fig. 14B).

Activity in subdiaphragmatic organs can interfere with evaluation of perfusion in 2 general ways. First, it can result in apparent increased activity in the adjacent inferior wall as a result of scatter and volume averaging. This can mask a true defect in the inferior wall or may lead to normalization problems throughout the remainder of the myocardium, due to the increased activity in the inferior wall.

Less intuitively, this adjacent "hot" activity can result in apparent decreased activity in the adjacent myocardium. This results from the reconstruction algorithm used in filtered backprojection (FBP). FBP attempts to limit the star artifact that arises from a simple superposition of backprojections of the data from the multiple angle acquisitions of a SPECT study. FBP uses a ramp filter, in which the

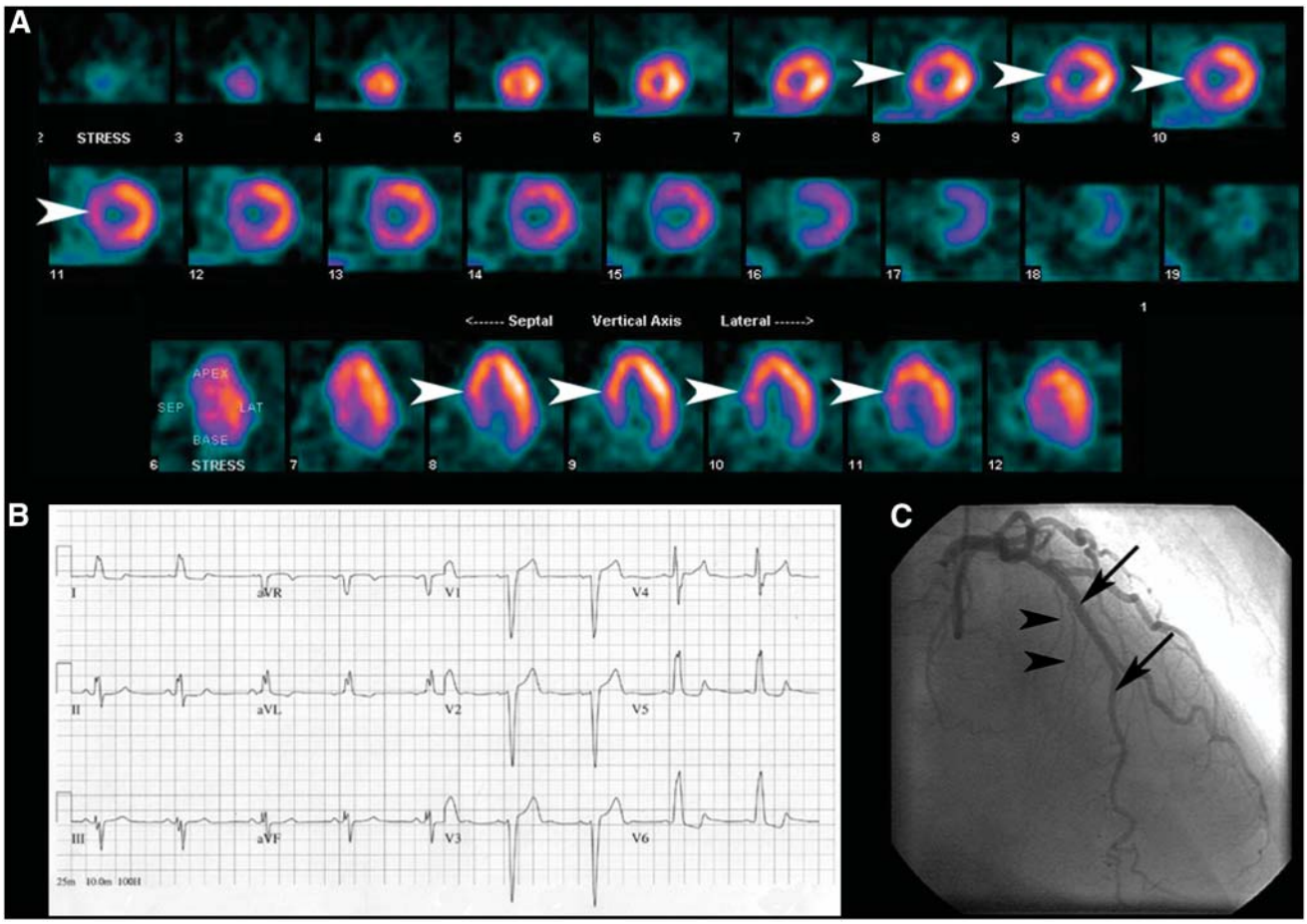

FIGURE 19. (A) Myocardial perfusion scan obtained after injection of ^{99m}Tc-sestamibi during episode of pain shows septal defect (arrowheads). (B) Patient's ECG reveals presence of LBBB. (C) Patient's coronary angiogram reveals normal vessels supplying the septum, including left anterior descending artery (arrows) and septal perforators (arrowheads), indicating that septal defect was secondary to LBBB.

weighting applied increases linearly as a function of frequency in the frequency domain (like a ramp) (Fig. 15A). In the spatial domain, this is represented by a decaying oscillation function (Fig. 15B) such that a negative weighting is applied at short distances away from a hot object (*11,23,24*). This results in the artifactual decreased activity adjacent to hot objects. In addition to the ramp filter, an additional filter, called a window, is applied, resulting in a combined filter such as a Butterworth filter. However, the phenomenon of decreased activity adjacent to hot objects persists. With respect to the influence on myocardial counts from hot subdiaphragmatic activity, the effect is worse the greater the subdiaphragmatic activity and the lower the cutoff frequency (*24*). Figure 16 illustrates a case in which the apparent perfusion to the inferior wall was much worse at rest than at stress, which is improbable physiologically. On the rest study there was intense activity in the adjacent liver. As demonstrated in the count profile, after FBP this has resulted in negative counts being assigned to the region adjacent to the liver, resulting in the apparent decreased perfusion to the LV.

Because subdiaphragmatic activity can result in either increased or decreased activity in the adjacent myocardium, clearly both influences may coexist. As they can exist on either the rest or the stress images, they may result in an artifactual fixed or reversible perfusion defect. It is not possible in any given case to know what the effect of this activity has been. The best solution is to avoid adjacent subdiaphragmatic activity altogether. Some have demonstrated that having the patient drink milk after the injection can reduce the activity in the liver (*25*), but this is not universally accepted in clinical practice. Having the patient drink water may help clear activity from the stomach (*25,26*). Prone imaging can help by displacing subdiaphragmatic organs away from the heart (*27,28*). In patients undergoing pharmacologic stressing, the addition of low-level exercise along with the pharmacologic stress can reduce adjacent subdiaphragmatic activity by increasing skeletal muscle blood flow and, thereby, decreasing splanchnic blood flow (*29,30*). One of the most important approaches, however, is to wait an adequate amount of time between injection of the radiopharmaceutical and imaging to allow subdiaphragmatic activity to clear. If there is significant subdiaphragmatic activity at the time of initial imaging, and if it might influence the interpretation of the study, a further delay to imaging is warranted. Figure 17 demonstrates such a case. Initially there is substantial hepatic uptake on the rest images, which renders it impossible to determine whether an inferior wall defect contains any reversibility. The patient was brought back for a repeat rest study with a longer delay between injection and imaging. There is no longer significant hepatic activity, and it can be confidently interpreted that there is no reversibility in the inferior wall defect.

The technologist plays an important role in identifying such potentially confounding activity while the patient is still in the department. When this may influence the interpretation of the test, the additional maneuvers described

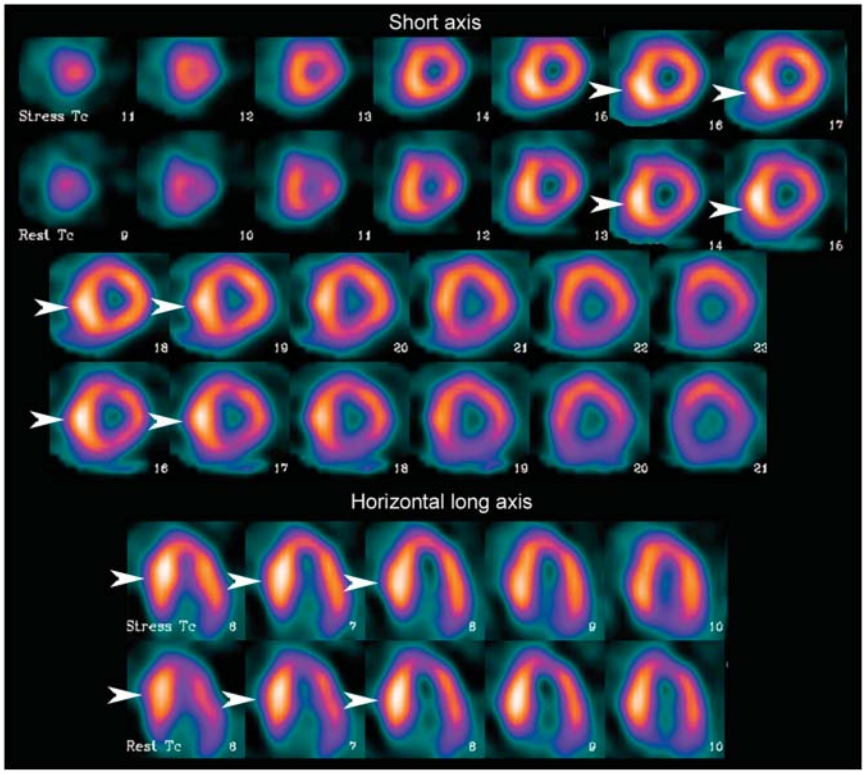

FIGURE 20. Myocardial perfusion scan in patient with hypertrophic cardiomyopathy. There is marked increased uptake in septum (arrowheads), which leads to the erroneous appearance of decreased perfusion to remaining walls.

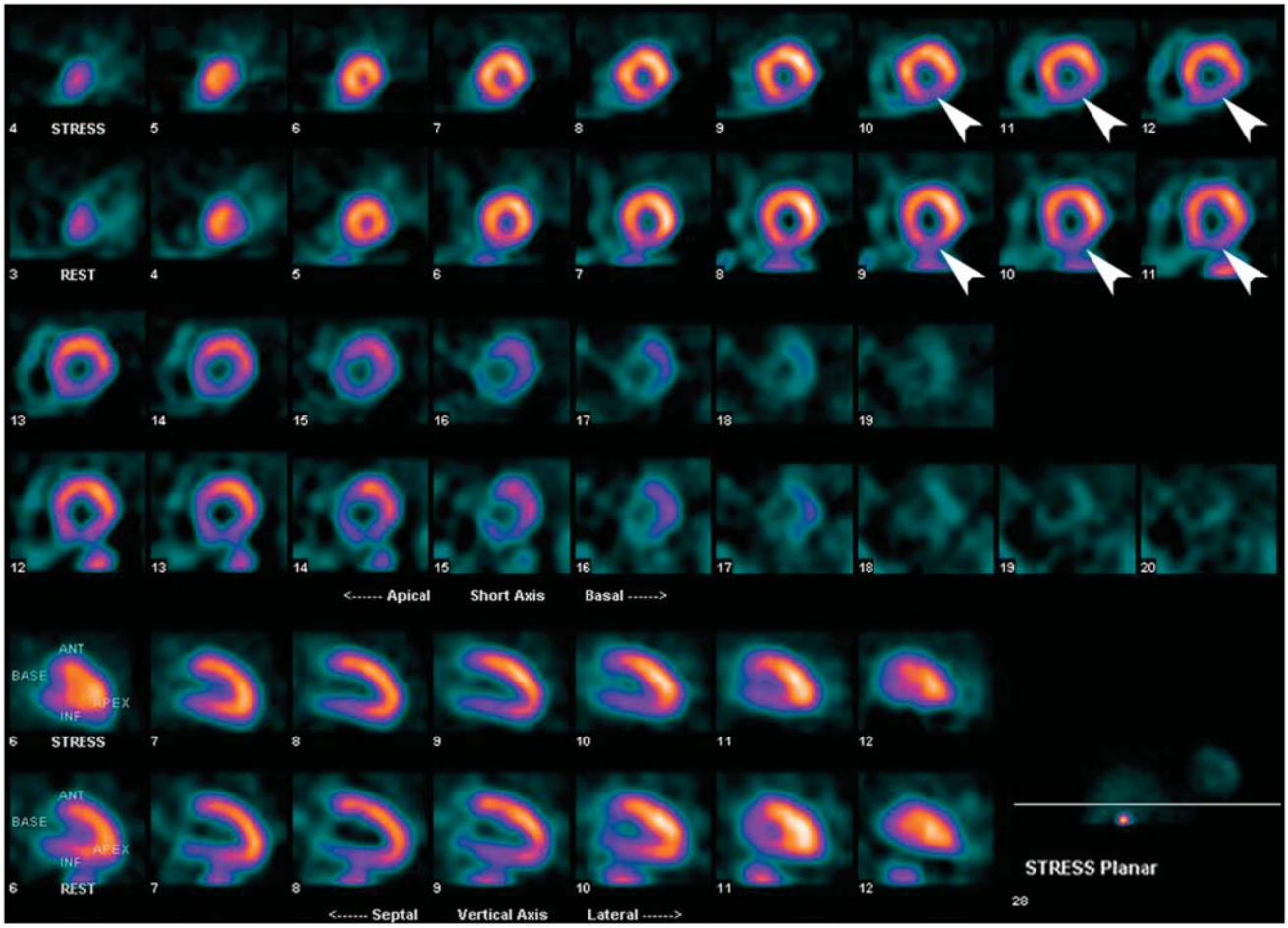

FIGURE 21. Myocardial perfusion scan reveals inferior and inferolateral defect (arrowheads) with only mild reversibility. However, patient had critical 3-vessel disease not evident on myocardial perfusion scan, likely a result of ''balanced ischemia''.

should be considered, in consultation with the interpreting physician if necessary. This may prevent having to bring the patient back for a repeat study, as was done in the case described here.

HEART-RELATED ISSUES

Left Bundle Branch Block (LBBB)

The normal conduction system of the heart is shown in Figure 18A. An impulse originates in the sinoatrial (SA) node. It travels through the right atrium to the atrioventricular (AV) node. It then divides to travel down through the septum along the right and left bundle branches, and subsequently onward to the right ventricle and LV, respectively, to initiate contraction. LBBB is a conduction abnormality in which the signal cannot pass through the left bundle branch, as shown in Figure 18B. In this situation, conduction to the LV comes from the right ventricle and is delayed. This results in paradoxical septal motion (toward the right) on gated studies. More importantly, it can result in a septal defect on perfusion imaging, which may be mistaken for myocardial infarction or ischemia, depending on whether the artifactual defect is fixed or reversible. The mechanism for the apparent defect has not been completely established but likely results from compromise of diastolic blood flow due to the delayed septal contraction (*31*). This compromise is accentuated by increasing heart rate and, thus, is less common when using vasodilator stress with dipyridamole or adenosine than with exercise stress (*3,32*).

The presence of LBBB is readily established from the ECG. However, this does not mean that a perfusion defect in the septum in a patient with LBBB is necessarily due to the LBBB rather than coronary artery disease; hence, this can present a diagnostic dilemma. Figure 19A demonstrates a perfusion defect in the septum in a 74-y-old woman injected with ^{99m}Tc-sestamibi during an episode of chest pain. She has a LBBB, as shown on her ECG (Fig. 19B). Her coronary angiogram (Fig. 19C) reveals a normal left anterior descending artery and septal perforators, which are responsible for supplying the septum. This confirms that the defect in this patient is indeed artifactual secondary to the LBBB.

Hypertrophic Cardiomyopathy

Cardiomyopathies are a group of diseases in which the primary abnormality directly involves the heart muscle

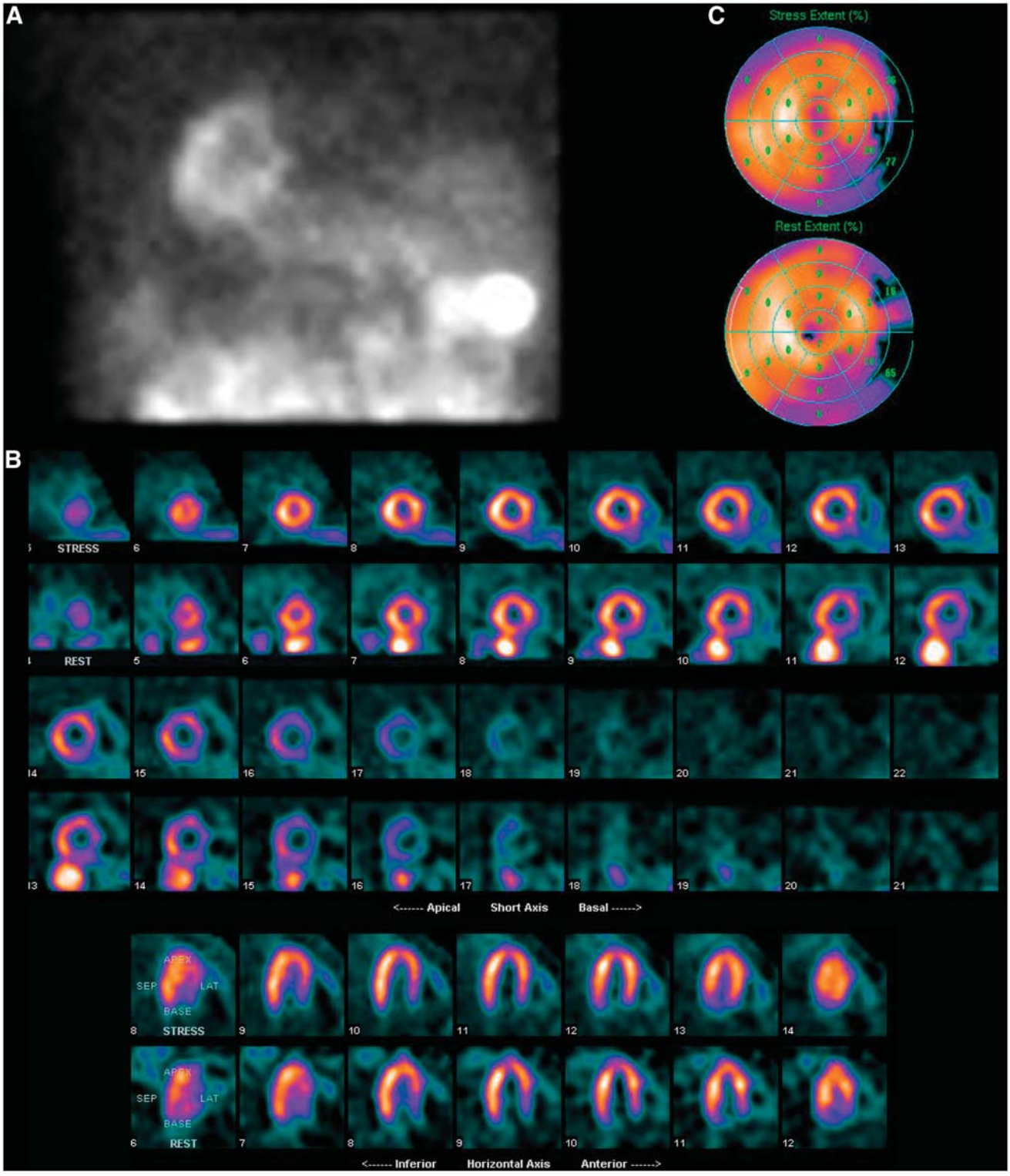

FIGURE 22. (A) Anterior frame from raw data in patient with dextrocardia. His abdominal organs are also reversed left to right (situs inversus). (B and C) Myocardial perfusion scan (B) and quantitative analysis (C) from the same patient. A defect is erroneously identified in what is usually the lateral wall, as this is actually the interventricular septum in this patient. There are no true perfusion defects on this study.

itself (*33*). Cardiomyopathies are classified as ischemic or nonischemic, with nonischemic further classified as dilated, hypertrophic, or restrictive. In hypertrophic cardiomyopathy, there is thickening of the myocardium, often particularly involving the septum. This can result in significant increased activity in the septum, which results in the activity in the other walls appearing decreased. This may lead to the erroneous diagnosis of widespread perfusion abnormalities. This phenomenon can also be seen in the setting of hypertension, though it is less frequently seen and is typically less severe in this circumstance.

Figure 20 shows the perfusion images from a 35-y-old man with hypertrophic cardiomyopathy. There is marked increased uptake throughout the septum, which, because of the normalization to the hottest pixel, results in apparent widespread decreased perfusion to the remaining walls of the LV.

Balanced Ischemia

The preceding case illustrates one of the limitations of MPI with SPECT: This technique can only measure relative uptake, not absolute activity. This limitation is responsible for another potential pitfall, underrecognition of multivessel disease. If there is decreased perfusion to all walls, the abnormalities may not be recognized, particularly if the decrease is of a similar magnitude throughout (so-called "balanced ischemia"). Still, whereas the sensitivity for identifying multivessel disease in patients with 3-vessel disease is only approximately 60% (*34*), there is usually some abnormality present, so that the identification of some degree of coronary artery disease in this setting remains high, at 95%–98% (*35*).

Figure 21 shows the perfusion images from a 64-y-old man. The stress images reveal a moderate defect in the inferior and inferolateral walls, with just a small amount of reversibility on the rest images. However, on the gated studies, there were extensive wall motion abnormalities on the poststress gated study, with an EF of 32%, whereas on the rest gated study there had only been a wall motion abnormality in the inferior wall, and the EF had been 49%. This suggested there had been extensive postischemic stunning, as a result of unrecognized widespread ischemia and, indeed, the patient's coronary angiogram confirmed critical 3-vessel disease.

Dextrocardia

It is essential that the presence of dextrocardia be recognized by both the technologist and the reporting physician. This situation may not be known when the patient presents for a myocardial perfusion study. Because of the altered orientation of the heart within the thorax, a 180° SPECT acquisition will have to range from −135° to +45°. The orientation will also have to be considered during the processing.

The interpreting physician must be made aware of the dextrocardia to avoid errors in interpretation of the study. Figure 22 shows a myocardial perfusion study in a 66-y-old man with dextrocardia. The altered orientation results in an apparent defect in what is normally the lateral wall. However, in this case that wall is actually the septum, and the perfusion is normal. This pitfall is reiterated in the quantitative analysis, which does not allow for the dextrocardia, with an apparent lateral wall defect being highlighted.

CONCLUSION

There are several artifacts and interpretation pitfalls that can potentially compromise MPI. These may be related to the patient, the equipment, or the technologist. It is essential for both the technologist and the interpreting physician to be aware of these potential sources of error, take appropriate steps to limit them beforehand, where possible correct them if they do occur, and, when they cannot be eliminated, recognize their potential impact on the interpretation of the study. This will ensure MPI retains its important role in the management of patients with cardiovascular disease.

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