Myocardial perfusion planar imaging

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Although single photon emission computed tomography (SPECT) is preferable for myocardial perfusion scintigraphy, in a minimal number of circumstances, planar imaging may be useful or may be the only modality available.

Purpose. To evaluate regional myocardial perfusion and function. Planar imaging is an acceptable method for myocardial perfusion imaging. The anatomy of the heart is sufficiently simple that the imaging specialist can comprehend the location and extent of defects from multiple projections without need of computer reconstruction. Although SPECT imaging is presently considered state-of-the-art for myocardial perfusion imaging and preferable, planar imaging still has a role in the daily routine of a laboratory. Imaging at the bedside of acutely ill patients, or instrumented patients, can only be performed using planar imaging technique and portable gamma cameras. Planar views can be quickly repeated if the patient moves during acquisition. Planar imaging may be the only way to acquire images in very obese patients, who are too heavy for the imaging table of a SPECT camera. It may also be the only way to acquire images in severely claustrophobic patients.

Electrocardiography (ECG)-gated planar images can be obtained using standard software for equilibrium radionuclide angiography studies. Finally, planar imaging is the basis for good SPECT imaging. The ability to obtain high-quality planar images is an essential skill, even for those who routinely use SPECT imaging.[1]

PROCEDURE

Exercise

Adequate exercise is most important if the aim of the study is to detect coronary artery disease (CAD). In patients with mild and moderate CAD, myocardial blood flow may become abnormal only at high heart rates or at high double products. At lower heart rates, myocardial blood flow may be normal and perfusion images will be correspondingly normal. In patients with known CAD who are being evaluated for extent and severity of inducible myocardial ischemia, submaximal exercise can provide clinically relevant information.[2]

Positioning

The most important part of positioning is the ability to reproduce the same position on initial and delayed (or rest) images. Even slight differences in angulation of the camera, positioning of breasts or other soft tissue, or the pressure of the camera on the chest wall can produce artifacts and inaccuracies in comparing rest and stress images. It is vital to bring the camera head as close to or touching the patient's chest in order to get the highest possible count rates, as opposed to SPECT imaging, where some distance is necessary to avoid collisions with the patient during rotational acquisition.

The standard imaging positions are supine anterior, supine 45° left anterior oblique (LAO), and a right side-decubitus 90° left lateral (LL). The 90° LL decubitus view provides optimal visualization of the inferior wall and reduces subdiaphragmatic and breast attenuation artifacts. Admittedly, the right-side decubitus position is less stable than the supine position, making it somewhat more difficult to obtain identical repositioning. An alternate LL view is the shallow 70° LAO position. The latter position is suboptimal at times due to frequent occurrence of artifacts: subdiaphragmatic attenuation of the inferior wall and breast attenuation of the anterior wall.[3]

The LAO view should be chosen in such a way that the right ventricle and left ventricle are well separated by a vertically visualized septum (i.e., ''best septal'' view). One should be aware that in individual patients the heart may not always be in the same position. Hearts may be rotated clockwise or counterclockwise so that a ''straight'' 45° LAO will not always display the desired image. It is preferred to search for the ''best septal'' view instead of a straight 45° LAO. The angulation of the detector head for acquisition of anterior and LL views should then be correspondingly modified. The advantage of this option is that it provides greater

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standardization of the imaged left ventricle, which will simplify quantitative analysis. The disadvantage of this option is the increased complexity, and it carries the potential for non-reproducible positioning.

Female patients should be imaged consistently with the bra off and without camera pressure, which might produce variable tissue displacement.

Planar imaging may be particularly useful in patients who are unable to maintain the supine position for a prolonged period of time. New camera designs allow for imaging in upright or seated position. As for supine acquisition, images are to be obtained in multiple views as listed in the table below. Position of cameras and patients must be exactly reproduced for rest and stress imaging, whether supine or upright.

Positioning

View	Patient position	Detector position	Alternative
Shallow LAO	Supine/upright	45°	"Best septal"
Anterior	Supine/upright	0°	"Best septal" minus 45°
Steep LAO	Supine/upright	70°	"Best septal" plus 25°
Left lateral	Right decubitus or upright	0° or 90° if upright	Not applicable

Positions of cameras and patients must be exactly reproduced for rest and stress imaging.

IMAGE ACQUISITION

Gamma camera positions are as shown in the previous table. Using either thallium 201 (Tl-201) or technetium 99m (Tc-99m)-labeled agents, one may optionally use ECG-synchronized gating and acquire in 16-frame, multiple-gated acquisition (equilibrium radionuclide angiography) mode. No beat rejection should be used. In patients with atrial fibrillation, ECG gating should not be performed. ECG-gated acquisition allows for cine review of wall thickening and motion. The multiple frames of the ECG-gated myocardial perfusion images can be summed to produce a single static planar image for conventional visual and quantitative analysis.[4]

The total imaging time for static planar Tl-201 imaging should be 8 to 10 minutes per view, whereas the total imaging time for static planar Tc-99m-labeled agents can be reduced to 5 minutes per view. When ECG gating is used, imaging time per view using Tc-99m agents should be extended to 8 to 10 minutes. For ECG-gated image acquisition with Tl-201, image acquisition time per view should be at least 10 minutes per view. Planar images acquired with a 10-inch-diameter gamma camera should have at least 600,000 counts (1 million counts preferred) in the field of view. Alternatively, optimal count density can be defined as at least 100 counts in the pixel with maximal counts in the left ventricle.[5,6]

In female patients an optional 1-minute image of a line source marker that delineates the contour of the breast can be acquired to aid in identifying breast attenuation artifacts.

Cardiac shields or other masking devices should not be used. The extracardiac background cannot be determined correctly unless both the cardiac activity and extracardiac activity have been recorded in the raw data.

Acquisition

	Tc-99m	Tl-201
Collimator	High resolution	Low energy, medium resolution
Field of view	Full 10-inch field of small camera or 1.2-1.5 zoom with large-field-of-view camera	Same
Matrix	128 × 128	128 × 128
Window	140 keV 20% centered	78 keV, 30% centered
Gating	Optional 16 frames/ cardiac cycle	Same
Imaging time (per view)	5 minutes (10 minutes ECG-gated)	8-10 minutes (10 minutes ECG-gated)
Imaging counts	At least 1 million	At least 1 million

QUANTITATIVE PROCESSING OF PLANAR IMAGES

Quantitative processing includes using the computer to produce standardized raw images for visual evaluation. The gray scale should be fully utilized to display the heart normalized to maximal left ventricular (LV) count density, and not scaled to visceral activity.

Background subtraction is performed. The background-subtracted images are useful for visual evaluation and are used for measurements of myocardial activity. These measurements provide quantitative determination of a suspected defect so that consistent standards can be set for defect detection. The measurements are especially useful in comparing defects in stress and rest images and to detect subtle defect reversibility. Registration of the stress and rest images also can be performed to ensure that the same myocardial region is being sampled. A normal database also may be incorporated in the quantitative program so that segmental tracer activity can be compared with the average obtained from the normal database.[7-11]

There is no single ''generic'' description for what all good computer programs should offer. There are common features among several successful programs. In the following section we review these features and comment on acceptable variations.

Regions of Interest

The first step in quantification is to locate the heart by placing reference regions of interest around the heart. Regions can be rectangular or elliptical. Elliptical regions fit the heart better. Rectangular regions are best used by having the operator set the boundaries by touching the apparent ''edge'' of the heart and then moving the region outward approximately 4 pixels. This operation is highly reproducible. The reference boundaries are used to separate the region containing myocardial activity from background activity.

Background Subtraction

Background subtraction is the removal of the background or, more precisely, the ''tissue cross-talk'' from the raw image. For each image, a background image is generated from the smoothed image using the above-mentioned reference background region. The background is then subtracted from the unsmoothed raw image, leaving behind the myocardial activity.

Background subtraction is essential to planar imaging both for valid quantitation and to restore defect contrast adequate for visual assessment. Background correction is in fact more critical for planar imaging with Tc-99m-labeled agents than for imaging with Tl-201. The relative tissue distribution of Tc-99m-labeled agents at rest and after exercise may be markedly different compared to that of Tl-201.[12]

A modified version of the conventional interpolative background algorithm has worked well for both Tl-201 and Tc-99m sestamibi planar images. The modification allows the background-defining regions to cross regions of intense extracardiac activity without causing significant background error in the background-subtracted cardiac image.[13]

Rescaling the Image Gray Scale

When Tl-201 is used as the imaging agent, the heart is usually the organ with the most intense activity. When using myocardial tracers labeled with Tc-99m, activity in the abdominal viscera often exceeds that of the heart. This normally causes the computer to scale image intensities to the extracardiac activity, which will cause erratic and suboptimal visualization of the heart. Any computer program for quantitative image processing should have a convenient mechanism to suppress activity outside the heart if it becomes greater than the activity in the heart. When comparing initial and delayed images or images obtained after reinjection, each image should be individually scaled to the area of most intense cardiac activity. If the images were scaled to different maxima, the appearance of defect reversibility would be distorted.

Image Registration

Comparison of rest and exercise images to detect redistribution or reversibility can be accurate only if the same myocardial segments are being compared. Image registration so that stress and rest images are precisely aligned facilitates accurate comparisons. There are several ways of doing this. Maximizing the cross-correlation coefficient between the two images is a robust method that can be performed by the computer without operator intervention.

Profile Generation

After subtraction of the reference (background) plane to compensate for tissue crosstalk and registration of the images to allow precise comparisons, quantification becomes the relatively simple matter of finding a convenient way of indicating image count density. Again, there are several ways of doing this. One basic way is to display count profiles across the heart. Four profiles will sample the myocardial count distribution adequately within the limitations of image resolution (each profile represents an average of about a 1-cm-wide slice across the heart) and produce an intelligible display. A more commonly used alternative for graphic display of myocardial activity is the circumferential count distribution profile. The circumferential profile method provides a more compact and dense single-curve display of counts sampled around the myocardial ''rim'' and allows the simple plot of a second profile indicating normal limits. Either method, transverse count profiles or circumferential count profiles, will provide an adequate and ultimately equivalent quantitative representation of myocardial activity. Either method facilitates standardization and reproducibility of image interpretation.[14]

A more fundamental choice is what parameter to use to quantify myocardial activity. Many programs, including most methods used to generate bull's-eye maps for SPECT imaging, perform a search across the myocardium for the maximum pixel count in a transmural myocardial sample. The other choice is to take an average of counts in the transmural sample. The advantage of the latter method is that it reduces statistical noise because it is an average, and it is intuitively more representative in regions of subendocardial scar or ischemia. The disadvantage is that the transmural average is quite sensitive to the accurate definition of endocardium and epicardium. Variability in locating the epicardial and endocardial limits probably nullifies the gain in precision from the averaging of more pixels. The use of maximum counts provides a quantitative parameter that is less sensitive to edge location. This parameter has been used extensively and has been reasonably robust in practice. Either method is usable. Normal standards and normal limits will be quite different for those using the transmural average. They are not comparable with values based on transmural maximum.[15]

Normal Database

Data from ''normal'' subjects may be incorporated into the computer program and indicated in the output as normal limits. Because of variations in equipment and positioning, the normal database should not be used until it has been validated in-house using standardized imaging protocols.

Along with the average values obtained from the normal database, the standard deviations (SDs) also need to be obtained. Different myocardial segments will have different degrees of normal variability, which should be accounted for in deciding if a segment is outside normal limits. Individual segments may be flagged using limits of 2.0 to 2.5 SDs. The computer may also flag reversible segments, but this is a more complex operation. The database must have SDs comparing stress and rest segments. If a segment has a significant stress defect, reversibility may be indicated if that defect changes toward normal by more than 1 SD. Additional ''expert logic'' may also be incorporated to scan for secondary segments with nonsignificantly reduced initial uptake and significant reversibility.[1,16]

Limitations

Well-trained readers consistently outperform readings even from relatively sophisticated computer programs. The programs are valuable in standardizing the images and image processing and in maintaining consistent interpretive standards. However, the judgment of a well-trained reader should override the computer logic. Computer programs that dogmatically indicate normal and abnormal scans or scan segments can be intimidating and misleading. Readers must be prepared to disagree and overrule the computer. Otherwise, the readers will be no better than the computer.

INTERPRETATION AND REPORTING

Images should be assessed initially for technical adequacy, including target-to-background activity, splanchnic tracer uptake, count adequacy in the cardiac region of interest, adequacy of count normalization and masking, appropriate orientation of the planar projections, and registration of the stress and delay (Tl-201) or stress and rest (Tc-99m agents) planar projections and appropriate location and alignment of the ventricular region of interest utilized for quantitative analysis, if performed.

Display

Planar perfusion images may be displayed by use of the computer screen, x-ray film, or paper copy. The use of the computer screen is strongly recommended and is the preferred medium. Counts should preferably be represented by a linear gray scale. If a color table is used, the scale should be simultaneously displayed on screen. Otherwise, the adequacy of the display medium (film or paper) should be established by inspection of a standard test pattern, which provides testing of both resolution and gray scale.

The initial set of images is typically displayed together with the subsequent set of images aligned adjacent to or underneath it. The interpreting physician should confirm that the imaging angles have not changed between image sets. Images are typically normalized to themselves. Planar images should be interpreted without any processing. Background-subtracted images may be generated for quantitative analysis but should not be interpreted without viewing the unsubtracted images as well.

Evaluation for Technical Sources of Artifacts

The images should then be carefully inspected for potential image artifacts, the most common of which is attenuation.[17] Suspected soft-tissue attenuation should be thoroughly evaluated and its effect on the interpretation carefully considered. The use of breast marker images may be helpful in distinguishing true perfusion defects from breast attenuation.[18] Attenuation of the inferior wall by the diaphragm or an enlarged right ventricle should also be considered. Other sources of attenuation (e.g., pleural effusions or infiltrates, foreign objects, other soft tissues) should be noted.

Adjacent subdiaphragmatic activity, as is frequently seen in liver and bowel, may create overlap artifacts that spuriously increase the activity in the inferior wall, creating the appearance of a relative paucity of counts in other myocardial segments. Intense noncardiac activity may cause scaling artifacts in the myocardial images. Techniques for masking such noncardiac activity are available.

Count-poor studies are subject to misinterpretation. Apparent perfusion abnormalities may resolve when a statistically adequate study is available. The factors leading to suboptimal count statistics include body habitus, radionuclide dose, collimation, window, acquisition time, and the level of myocardial blood flow.

Patient motion is rarely a problem because of the short duration of imaging.

Initial Perfusion Image Analysis and Interpretation

The initial interpretation of the perfusion scan should be performed without any clinical information other than the patient's gender, height and weight, and presence of left bundle-branch block. This approach minimizes the bias in study interpretation. All relevant clinical information should be reviewed after a preliminary impression is formed.

Before segmental analysis of myocardial perfusion, the reader should note whether there is LV cavity dilation at rest or during exercise or pharmacologic challenge. Dilation on both the stress and resting studies suggests LV dysfunction but may occur in volume-overload states with normal ventricular function. Transient ischemic dilation is a marker for multivessel CAD. It is typically described qualitatively but may be quantified.[19]

The presence of increased lung uptake should be noted by comparison of the pulmonary to myocardial counts. This is especially important when imaging with Tl-201. Although qualitative assessment is standard, calculation of lung-to-heart ratios is preferred. Lung uptake may be increased on stress images if the exercise was submaximal. Lung uptake during dipyridamole and adenosine imaging tends to be higher than that seen during adequate exercise. Both the likelihood of CAD and the risk of an adverse outcome are increased when lung uptake is increased.

Right ventricular (RV) intensity is normally about 50% of the peak LV intensity. Increased RV uptake is indicative of RV pressure overload, most typically because of pulmonary hypertension. RV intensity may also appear increased when LV uptake is globally reduced.

The images should be examined for the presence of activity in organs other than the heart and pulmonary vasculature. Thyroid uptake, breast uptake, pulmonary parenchymal (tumor) uptake, or uptake in other thoracic or upper abdominal structures should be noted. Hepatic or splenic enlargement and the apparent absence of a gallbladder on technetium studies may be of clinical significance.

A statement regarding the overall quality of the study is helpful for two reasons. First, it alerts physicians using the report to any shortcomings that might reduce the accuracy of the data and their interpretation. Second, it is useful as an inclusion/exclusion criterion for subsequent acceptance of the study for research or other statistical analyses.[20]

Segmental Perfusion Assessment

The detection and localization of perfusion defects is typically performed by use of visual analysis of the unprocessed images. Perfusion defects are assigned to a particular myocardial segment or segments. Standardized nomenclature is recommended (Figure 1). In the anterior planar image, the anterolateral and inferior walls are divided into basal (1 and 5), and mid (2 and 4) segments, and the apex (3) separates the inferior and anterolateral walls. In the LAO view, the septum is divided into anteroseptal (6) and inferoseptal (7) segments, whereas the lateral wall is divided into inferolateral (9) and anterolateral (10) segments, and the inferior segment (8) separates the septum from the lateral wall. In the lateral view, the anterior and

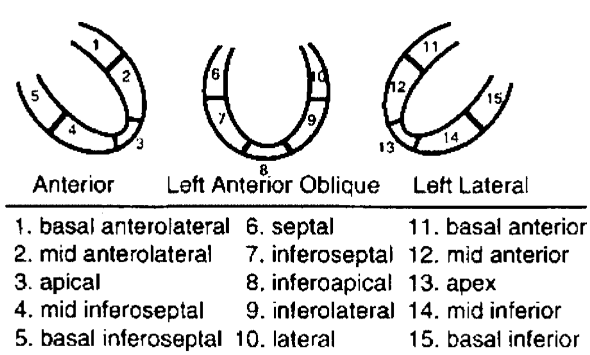

Figure 1. Planar MPI segmentation.

inferior walls are divided into basal (11 and 15) and mid (12 and 14) segments, whereas the apex (13) separates the anterior and inferior walls. Perfusion defect severity is typically expressed qualitatively with terms such as mild, moderate, or severe. Defect extent may be characterized qualitatively as small, medium, or large.

Rather than the qualitative evaluation of perfusion defects, it is preferred that the physician apply a semiquantitative method on the basis of a validated segmental scoring system. This approach standardizes the visual interpretation of scans, reduces the likelihood of overlooking significant defects, and provides an important semiquantitative index that is applicable to diagnostic and prognostic assessments. Furthermore, semiquantitative scoring can be used to more reproducibly and objectively designate segments as normal or abnormal. A 5-point model has been recommended for semiquantitative scoring of segments.

Category	Score
Normal perfusion	0
Mild reduction in counts—not definitely abnormal	1
Moderate reduction in counts—definitely abnormal	2
Severe reduction in counts	3
Absent uptake	4

The summed scores may also be calculated by adding all segment scores together to provide an integrated index of severity and extent. This may be done on the initial and resting or delayed images, and a summed difference score could then be used to represent the amount of defect reversibility.[21]

Perfusion Defect Severity and Extent: Quantitative

Quantitative analysis can be useful to supplement visual interpretation of the images. In planar perfusion imaging, quantitative analysis requires that a background subtraction be applied. The physician should review the background-subtracted images for technical adequacy. Quantitative data may be displayed as graphs of counts versus angular sampling location or as profiles that compare counts in contralateral walls of each image. Supporting data exist for both approaches. When counts are graphed versus radial sampling location, the resultant curve is typically compared with a gender-matched, reference database. The 2.0- to 2.5-SD curve is usually graphed with the patient's curve, and segments where the patient's curve drops below the reference curve are considered abnormal. The area between the patient's curve and the reference curve is a quantitative index of the combined extent and severity of the perfusion abnormality.[7-9]

Separate gender-based reference databases are recommended for thallium and technetium-based perfusion agents because the myocardial distribution and, in particular, the extracardiac activity are significantly different. Separate databases are also preferred, when available, for pharmacologic and exercise studies. Quantitative analysis of the data should not be used as a surrogate for visual analysis but rather as an expert opinion that may be used to modify the physician's impression.

Reversibility of perfusion defects may be categorized qualitatively as minimal, partial, or complete. Reversibility can be defined quantitatively as defects in which pixels improve to fewer than 2.5 SDs from the normal reference distribution at that location. The number of pixels that must show improvement for reversibility to be deemed present is arbitrary.

The so-called reverse redistribution may be seen in stress-delayed thallium imaging sequences. Reverse redistribution refers to segments with decreased or normal intensity on the initial set of images that show even less relative intensity on the delayed images. The interpretation of the finding remains controversial.

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