QUALITY ASSURANCE FOR SPECT MPI

OBJECTIVES

Upon completion of the program, participants will be able to:

- Identify ICANL accreditation standards for MPI SPECT equipment QC to assure standard quality in nuclear cardiology imaging.
- Describe equipment QC guidelines set forth by ASNC, SNMMI, and SNMMI-TS.
- Explain how to perform equipment QC in a clinical lab to ensure standards are met.
- Describe image quality assessment during and immediately after a patient study.
- Define the current recommendations for attenuation correction.
- Recognize the challenges facing nuclear cardiology and the effect of a well established QA program.
- Explain where to locate more information on ICANL accreditation and ASNC, SNMMI, SNMMI-TS guidelines.

BACKGROUND

Quality Assurance is a formal program that evaluates the quality of care provided, while quality control is interpretive, administrative, or technical in nature.

Nuclear cardiology quality assurance encompasses a variety of processes including:

- Equipment quality control prior to patient imaging,
- Image assessment after the study is acquired, and
- A consistent final report.

A single issue with any of these variables can lead to an incorrect final interpretation and poor patient outcomes.

INTRODUCTION

Several organizations have set standards or put forth guidelines for myocardial perfusion imaging (MPI) quality assurance (QA) and equipment quality control (QC):

This program has compiled important portions of these guidelines and standards to help nuclear medicine technologists understand and perform essential nuclear cardiology QC procedures.

Shown here are the organizations which established these standards and guidelines.

- Intersocietal Commission for the Accreditation of Nuclear Medicine Laboratories (ICANL),
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- American Society of Nuclear Cardiology (ASNC),
- Society of Nuclear Medicine Molecular Imaging (SNMMI) and the
- SNMMI Technologist Section.

Published guidelines accepted by ICANL\(^1\) for Nuclear Cardiology imaging and QC refer to ASNC Updated Imaging Guidelines for Nuclear Cardiology Procedures – Part 1 and 2\(^2,3\) and SNMMI Procedure Guidelines for General Imaging.\(^4\)

In addition, this program includes additional references to further expand this information including:

- Notes on additional QC procedures,
- Issues surrounding attenuation correction, and
- Financial impact of improper QA/QC.

This educational program will focus on MPI single photon emission computed tomography (SPECT) imaging equipment standards and procedural guidelines.

### SPECT QC TESTS AND INTERVALS

An essential part of all QA is the records kept for current and retrospective analysis – often indicators for needed service when variances are noted.

Written records should always be maintained, including protocols for, and documentation of routine QC procedures, service, and maintenance on all imaging and non-imaging equipment.

Periodic assessment of imaging equipment quality- assures the equipment is in consistent, good working condition. Any QC not within standards stimulates timely action, and the variances and actions are noted in the records.\(^1,4\) QC intervals, which are recommended by ICANL, for SPECT imaging equipment, are identified here in Table 1.

<table>
<thead>
<tr>
<th>SECTION</th>
<th>TEST</th>
<th>PROCEDURE</th>
<th>INTERVAL</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>Energy Peaking</td>
<td>Radioisotope Source (appropriate for the energy of radioisotope being used)</td>
<td>Daily (documentation not required)</td>
</tr>
<tr>
<td>2</td>
<td>Uniformity</td>
<td>Intrinsic or Extrinsic Source; 2-5 Million Counts</td>
<td>Daily</td>
</tr>
<tr>
<td>3</td>
<td>Resolution &amp;</td>
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<td>Weekly</td>
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### Quality Assurance for SPECT MPI


<table>
<thead>
<tr>
<th>Linearity</th>
<th>High Count Calibration</th>
<th>Flood Source (&gt;30 Million Counts) for Uniformity Correction</th>
<th>Monthly, or per manufacturer recommendations</th>
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<tr>
<td>4</td>
<td>Center of rotation (SPECT)</td>
<td>Point Source</td>
<td>Monthly</td>
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<tr>
<td>5</td>
<td>Collimator Integrity</td>
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<td>6</td>
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<td>Manufacturer</td>
<td>Per Manufacturer’s Recommendation</td>
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<tr>
<td>7</td>
<td>Preventative Maintenance</td>
<td>Manufacturer</td>
<td>Every 6 months, or per manufacturer’s recommendations</td>
</tr>
</tbody>
</table>

Table 1: ICANL Recommended SPECT QC procedures and intervals.

Also noted in the ICANL standards is the need to repeat the procedures in Table 1, if equipment is moved from one location to another.

In addition, clear documentation and reasonable justification is required if intervals are less frequent from those stated.

### SPECT QC PROCEDURES

This general information is provided to demonstrate the minimum standards in the industry. Vendor specifications will often vary with each brand and type of equipment. Please check your equipment vendor’s recommendations in addition to the information in this course.

Effective July 1, 2010, quality control protocols must be reviewed and/or updated at least annually by the Medical Director, physicist or other responsible person.

Also, protocols for quality control must include acceptable range (or tolerance limits) of the results of each procedure and the corrective action for an out-of-tolerance result.

The results of quality control testing must be reviewed by appropriate staff in a timely manner and action taken if results are not within tolerance limits.
The protocols must contain instructions for record retention, and comparison with previous results.

*Note: In the following slides, the information provided in italics is an adjunct to the minimum ICANL Standards for Myocardial SPECT QC – but is often recommended in SNM/ASNC procedural guidelines.*

### 1. ENERGY PEAKING: DAILY

This test confirms the imaging system is counting the photon with the correct energy. Predominantly, technetium-99m (Tc-99m) or thallium-201 (Tl-201) is used for Myocardial Perfusion Imaging (MPI) SPECT. Prior to imaging, the appropriate radioactive point source is placed at a distance (1.5+ meters) from the imaging system, or a sheet source can be used directly in front of the detector face.

The imaging system should be peaked using the energy spectrum display according to manufacturer’s directions. The energy windows are set to be symmetric about the photopeak. A window of about 20% is recommended for Tc-99m, while a 30-35% window is recommended to accommodate the low energy and greater width of Tl-201’s photopeak. Verification of correct window settings and spectrum shape should be done, even with an automatic peaking system, as these settings tend to drift.

*Note: According to the ASNC Guidelines, photographs of the spectra and energy window should be taken and stored. Minimally, notations should be made that the equipment was properly peaked according to the protocol. However, ICANL Standards do not require documentation.*

### 2. UNIFORMITY TEST: DAILY

An intrinsic uniformity test (without collimator) or extrinsic uniformity test (with collimator) should be performed *daily, prior to use*, to confirm the imaging system’s uniform sensitivity across the imaging field of view.

Both intrinsic and extrinsic tests require the imaging parameters shown here:

- Visual inspection - 128X128 or 256X256 matrix with a 2-5 million count flood field parameter should be acquired.
- Photographs or computer images should be stored for day-to-day comparison of any variances.
- Variances are noted and may require service.

**INTRINSIC UNIFORMITY TEST**

Intrinsic uniformity is done without the collimator and with a uniform flood source to confirm that the imaging system’s sensitivity is uniform across the face of the detector.

Preferably, a radioactive point source is placed at a distance of at least 5 times the crystal’s useful field of view (FOV) from the center of the detector’s face.
The source should consist of the radioisotope predominantly used during imaging, in a point source of 200-300 uCi (up to 600 uCi for a large rectangular detector) in a small volume of about 0.5 ml.

**Note:** A simple intrinsic sensitivity test can be performed at the same time as the intrinsic uniformity test. This shows any variances in the imaging system’s sensitivity to the radioisotope. A point source is used at exactly the same distance in front of the camera for repeated measurements of counts per minute.

### EXTRINSIC UNIFORMITY

When intrinsic uniformity is difficult due to imaging system complexities, an extrinsic (with collimator) uniformity can be done.

The purpose of this test is the same as with the intrinsic uniformity but some minor uniformity issues can be obscured or confused with collimator uniformity issues. If aberrancies are seen in the extrinsic uniformity image field, an intrinsic uniformity test may be required to differentiate the source of aberrancy.

An extended-use, solid radioactive sheet flood source (typically Cobalt 57) is best for this daily test. Ideally the count rate should be between 20 and 30 kcps. This varies with the source and age of the detector.

If a fillable flood source is used, extreme care should be taken to mix the radioisotope uniformly. A lead ring should be used if available, to shield the outermost tubes from edge packing.

### 3. RESOLUTION & LINEARITY: WEEKLY

To check the system’s spatial resolution and its ability to reproduce straight lines over time, resolution and linearity is checked and compared to previous results on a weekly basis.

A bar phantom is used between the detector head and a uniform flood source without the collimator on (intrinsic acquisition). Bar phantoms are available commercially and most are acceptable for this test.

These include the 4 quadrant, orthogonal hole, and parallel-line-equal-space (PLES) bar phantoms. Rotating the 4-quadrant phantom $90^\circ$ each week provides comparison of each quadrant of the detector and allows repeated testing in each quadrant every 4 weeks.

A 256X256 matrix with a 2 to 5 million-count flood field should be acquired. Photographs or computer images should be stored for week-to-week comparison of any variances.

**Note:** To assess variances in resolution, the NMT should document the smallest bars that can be seen. Multiply the smallest bar by 1.7 times to determine the system’s spatial resolution at full-width-at-half-maximum (FWHM). To assess variances in linearity, the NMT visually determines and documents how straight the lines are. Variances from one week to the next are noted and service is called in if it is determined to be warranted.
4. HIGH COUNT CALIBRATION – UNIFORMITY CORRECTION: MONTHLY

The constancy of photon detection across the surface of the collimated detector is more important in SPECT than with planar imaging. Classic “ring” artifacts can occur in SPECT images, with either lighter or darker surrounding regions, in the transverse images. Perfusion image artifacts may also occur if left uncorrected especially when the variations are subtle.

Random fluctuations and corrected variations in camera response with rotation should be kept below 1%. Since current image system FOV non-uniformities are about 3%, this requires ‘correction’ to reduce the non-uniformities to under 1%.

A stored high count flood-field correction map is applied to the patient’s images prior to reconstruction. More than 30 million\(^1\) and up to 120 million\(^2\) counts are acquired in a 128X128 or 256X256 matrix. This is stored for uniformity correction for each imaging system as well as each collimator used for SPECT imaging. Care must be taken to use the same collimator for uniformity correction as is used during SPECT imaging and reconstruction.

Similar imaging energies for the flood source should be used, as with the imaging studies. Acceptable for Tl-201 and Tc-99m sources are: a Co-57 solid sheet source (at 122 keV) and Tc-99m fillable flood source.

A solid sheet source, which is verified uniform within 1%, is preferred and can be less problematic overall for daily use. However, a solid source requires periodic replacement and financial investment. If a fillable flood source is used, care must also be taken to mix the source very well to ensure the source itself generates a uniform energy across the detector head. A fillable flood source is far less optimal since the source’s uniformity itself cannot be confirmed.

5. CENTER OF ROTATION: MONTHLY

“Doughnut” (with 360\(^0\) orbit) or “tuning fork” (with 180\(^0\) orbit) artifacts occur in the transverse images when there is an alignment error between the mechanical center-of-rotation (COR) and the electronic matrix of the detector. This test assures the proper correction is included in the electronic matrix. Errors greater than 2 pixels in a 64X64 matrix are most significant and can cause false positives in a MPI study.

If more than one collimator is used for SPECT studies in a given lab, COR should be repeated for each collimator. In addition, COR values must be recalculated after image system service or software upgrades, which can eliminate the correct COR in the electronic matrix.

Manufacturer’s recommendations should be followed, if they are provided. If the manufacturer does not have a COR recommendation follow the procedure shown here:

- Prepare a 500-1000 uCi point or line source; place it on the patient table, 4 to 8 inches from the detector’s COR.
- Assure that the detector face is parallel to the axis-of-rotation.
- Acquire a rapid 360\(^0\) SPECT with equally spaced projections.
- Identical parameters for the patient acquisition should be used: the same collimator, angular orientation, matrix, zoom, and energy window. Sixteen to 32 views, at 5 to 10 seconds per frame are sufficient for COR.
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- This data is then processed in the computer software and stored for use during patient image reconstruction.

Note: According to ASNC guidelines the COR should be checked weekly for accuracy in an active SPECT program but ICANL standards require it be performed monthly.

6. COLLIMATOR INTEGRITY: ANNUALLY

This test is performed extrinsically, using a Co-57 sheet source. A minimum of 30 million counts is acquired, and the flood field image is visually inspected for any collimator issues.

Note: It is important to know not only the type of collimator (High Resolution, All Purpose, etc) used for MPI, but also know what the resolution is (FWHM at 10cm). Collimators can be called the same – but each manufacturer has resolution variances in their respective collimators. Typically, the low-energy, high-resolution collimator is used for Tc-99m imaging.

In addition, each collimator should be visually examined periodically for any physical damage that can occur during imaging system movement or while changing the collimators.

7. UNIFORMITY CALIBRATION

This test is performed according to the manufacturer’s recommendations.

8. PREVENTATIVE MAINTENANCE

Preventative maintenance is performed every 6 months or per manufacturer’s recommendations.

Note: The 2004 SNM Procedure Guideline for General Imaging suggests a periodic, high-count SPECT study with a uniformly filled cylindrical phantom to evaluate tomographic integrity. Spatial resolution and contrast can be evaluated when structures are inserted. A high count SPECT is acquired, and transverse images are created to determine the detector’s ability to see the various sized structures. Such phantoms come with recommended acquisition guidelines and should be followed. According to these guidelines, this procedure should also be done after equipment service has been performed.

QUALITY ASSURANCE OF MPI SPECT IMAGES

According to the ASNC/SNM guidelines, a number of procedures should be performed during and following image acquisition and processing to assure the best image quality. Avoiding patient movement, correcting for movement when it does occur, careful arm positioning, data review and correction should be routine imaging QA.
PATIENT MOVEMENT

Next to improper equipment QC, patient movement during imaging is the most common source of misalignment of the organ’s image. The cardiac cycle movement is unavoidable and is acceptable as a known source of image degradation. Additional image degradation occurs when the patient either moves during acquisition or experiences heavy breathing. Artifacts occur during reconstruction with motion during imaging. These artifacts can cause false results, which are often avoidable.

Patient observation is the first way to reduce movement. Irregular breathing should be avoided if possible, and talking and sleeping should be discouraged. The NMT should caution the patient not to move and have someone available to assist if the patient becomes restless or needs minor arm repositioning. Careful and guided assistance can help to keep the chest from moving – provided the arm is not moved significantly. Numerous devices are available commercially to assist with arm comfort and are well worth the investment.

DATA REVIEW

Prior to processing the patient image set, it is critical to view the raw rotating projection views in a cine format to observe any motion. Motion up or down in the cine display is most commonly detected, as this is perpendicular to the heart movement.

How much will this movement influence the results? This depends on the amount and location of motion within the cine series. With a single-camera SPECT system, a small amount of motion in the first frames and absence throughout the rest of the study will probably have little or no effect on the results.

This is not true with multi-headed systems – the movement will repeat at each camera interval within the cine. Motion in four or more frames in the middle of the cine may produce inferior or basal defects. If the patient moves toward or away from the camera, it is difficult to detect during review, but can also seriously impact the results.

If serious motion is detected (1 pixel or greater in a 64X64 matrix), manual methods can be used to shift the heart/frames back into the correct position. These methods, if available, will be a part of the image system software package and should be used as directed, and only if re-imaging the patient is not feasible.

The best procedure is to have the patient remain on the table after imaging while cines are displayed. If no motion is detected, the patient may be released.

If considerable motion is noted and a technetium-based cardiac radiopharmaceutical is used then the patient should be re-imaged as soon as possible.

If TL-201 is used, significant redistribution may have already occurred and the procedure may need to be repeated on another day. or a motion correction software algorithm may be applied.

ATTENUATION CORRECTION
Recently, attenuation correction has been loudly applauded for improvement of image quality, removal of artifacts, and ultimately increasing diagnostic confidence. However, concerns still exist if the technologists are not properly trained, a poor quality attenuation map is used, or the procedures are not followed accurately.\textsuperscript{6,6,7,8,9,10}

In 2004, the SNM and ASNC released this Joint Position Statement:

\textit{“On the basis of current information...(ASNC and SNM)...recommends that, when available and technically feasible, attenuation correction should be used in addition to ECG-gating with single photon emission computed tomographic (SPECT) myocardial perfusion imaging to maximize its diagnostic accuracy and clinical usefulness.”}\textsuperscript{8}

Clinical validation is recommended once hardware and software is acquired, and personnel are trained. This training increases awareness of potential negative outcomes if attenuation correction is improperly used. In addition, ACC/AHA/ASNC Guidelines 2003, suggest both attenuation corrected and attenuation uncorrected image sets are reviewed and integrated into the final patient report.\textsuperscript{6}

Scientific articles address concerns about proper technique. In March 2005, the JNM publication found that artifactual attenuation maps increased the number of false heart defects and myocardial infarct size. The authors concluded that visual inspection of the attenuation map’s quality is performed before implementation. The attenuation correction maps used should be accurate and free of artifacts to improve quality and increase diagnostic confidence.\textsuperscript{9}

Variations in procedures for each image system manufacturer do not allow for a concise review of how to perform attenuation correction. Some excellent synopses of these variances are available\textsuperscript{7,8,9} but lack the details needed to perform the procedures. It is suggested that the equipment manufacturer’s guidelines are followed for each type of equipment used.

### CHALLENGES FACING NUCLEAR CARDIOLOGY SURROUND QUALITY ASSURANCE

Several challenges have been identified by Bateman, et. al. relating to quality assurance.\textsuperscript{10} Payers and their policies lack recognition of quality in their verbiage and this is reflected in payment – or lack thereof – for the additional hardware and software required in a high quality nuclear cardiac environment.

Here is one of many examples of how ICANL standards are being reinforced by payers. Highmark Blue Cross Blue Shield announced the following as of January 1, 2005:

\textit{‘...all providers of diagnostic imaging services performed outside of a hospital setting will be required to adhere to new privileging guidelines. As detailed below, guidelines now exist related to each of the accrediting bodies within the Intersocietal Accreditation Commission: the ICANL, the ICAEL and the ICAVL.}
According to Augusta L. Kairys, Vice President of Provider Relations for Highmark Blue Cross Blue Shield, "These guidelines have been developed to promote reasonable and consistent quality and safety standards for the provision of imaging services."

However, the greatest motivator for imaging laboratories was the July 8, 2008 passing of the Medicare Improvements for Patients and Providers Act of 2008. (H.R.6331). This legislation includes a provision requiring accreditation of imaging facilities. The bill requires that by 2012, providers of advanced diagnostic imaging services, inclusive of Nuclear Medicine, MR, CT and PET must obtain accreditation as a condition of reimbursement.

Not only must the physicians and staff maintain the proper level of training and education, the laboratories must use imaging equipment which adheres to strict standards or performance, and operates under proper safety guidelines.

QUIZ

QUESTION #1

Any quality control performed on the equipment which results in significant variances from the standards or prior QC results:

- Should be documented prior to proceeding to image the first patient on the schedule
- Stimulates timely action for correction or service as is warranted and variances are documented
- Shuts down the lab; time to send the patients home until it is fixed and take a break
- Warrants a service call from the manufacturer

QUESTION #2

Minimum daily QC set by ICANL standards, includes the following procedures:

- Resolution and linearity
- Uniformity and energy peaking
- Data review
- Image assessment
QUESTION #3

Minimum weekly QC set by ICANL standards, includes the following procedures:

- Resolution and linearity
- Uniformity Calibration
- Energy peaking
- Collimator integrity

QUESTION #4

Energy peaking is performed daily:

- To assure the system is counting the photon with the correct energy
- By placing a radioactive point source directly in front of the detector face
- By placing a sheet source at a distance (1.5+ meters) from the imaging system
- Using a 30-35% energy window for Tc-99m

QUESTION #5

Extrinsic uniformity floods are:

- Acquired with the collimator off to determine the photomultiplier tube quality
- Acquired with the collimator on to determine the photomultiplier tube quality
- Acquired with the collimator on to determine the imaging system (collimator & photomultiplier tube) quality
- Done on a monthly basis

QUESTION #6

Intrinsic uniformity floods are:

- Acquired with the collimator on to determine the photomultiplier tube quality.
- Acquired with the collimator off to determine the photomultiplier tube & electronic equipment quality.
- Acquired with the collimator on to determine the imaging system (collimator & photomultiplier tube) quality.
- Done periodically
QUESTION #7

Resolution and linearity tests are performed weekly:

- With a flood source only
- To check the system’s spatial resolution and ability to reproduce straight lines
- Using a 1 million flood count.
- To check system’s ability to measure photon energy correctly

QUESTION #8

Classic ‘doughnut’ or ‘tuning fork’ artifacts occur:

- When the center of rotation is off by more than 2 pixels in a 64X64 matrix
- When the resolution has changed more than 2 pixels from the prior week
- In SPECT images, in either lighter or darker surrounding regions in the transverse images
- When a contaminated ring badge is dropped on the patient table at imaging time

QUESTION #9

According to ICANL standards, preventative maintenance is performed:

- Daily.
- According to camera manufacturer’s recommendations, or every 6 months.
- Weekly.
- Monthly.

QUESTION #10

Classic ‘ring’ artifacts occur when:

- When the resolution has changed more than 2 pixels from the week previous
- In SPECT images, with either lighter or darker surrounding regions in the transverse images
- A contaminated ring badge is dropped on the patient table at imaging time
- Center of rotation is off by more than 2 pixels in a 64X64 matrix
REFERENCES