Scintillation Camera Quality Control, Part I: Establishing the Quality Control Program

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This is the first article in a four-part series on scintillation camera quality control. This series of articles will include both theory and practical knowledge on setting up a quality control program, acceptance testing and quality control for planar, SPECT and special imaging procedures. On completion of this article the reader should be able to: (a) discuss the purpose of a quality control program; (b) know how to establish the performance criteria for a scintillation camera; (c) know how to design a quality control program; (d) be able to set up the schedule for the quality control program; (e) understand the economics of quality control; and (f) justify the expenditure of the institution's resources on quality control.

Key Words: quality control; quality control program; scintillation camera; performance criteria; design; scheduling economics

J Nucl Med Technol 1998; 26:9–13

This first article, of a four-part continuing education series on scintillation camera quality control, discusses how to establish the quality control program. Recommendations for scheduling and the economics of a quality control program are presented along with a justification of the costs, both monetary and personnel time.

The next two articles will discuss quality control for planar imaging including performance specifications, SPECT imaging and other special imaging procedures. Sequential and simultaneous imaging of dual radionuclides and coincidence imaging with dual-detector systems will be presented.

The final article in this series will discuss periodic quality control of performance specifications that typically drift slowly if at all, the computer and devices interfaced to the local area network and other accessories. In addition, the testing of the safety features of the imaging system and electro-mechanical and robotic features of the gantry will be reviewed. The required quality control procedures that should be performed before and after service calls and preventive maintenance also will be covered.

This series of articles is designed to provide an understanding of both the theory and a practical knowledge of how to implement, perform and interpret the results of quality control procedures. These articles will:

1. Explain why a procedure should be performed and how the specific characteristic to be tested affects system performance and image quality;
2. Discuss the theory behind the procedure to be performed;
3. Present the available phantoms and radiation sources that can be used to carry out the procedure;
4. Explain how to develop the reference criteria, both numerical and image based, to determine if the system is performing within acceptable limits;
5. Explain step-by-step how the procedure is to be performed; and
6. Provide images and/or numerical examples demonstrating normal and abnormal operation of the system whenever possible.

PURPOSE OF THE QUALITY CONTROL PROGRAM

Quality control procedures are performed before imaging with the scintillation camera to ensure, on a daily basis including weekends and holidays, that the camera is operating at or near the initial performance level when the camera was installed. This is a key factor in providing the best possible diagnostic study and patient care. Ideally, daily quality control procedures should take less than 10–15 min per scintillation camera detector and can be performed simultaneously for multiple cameras and detectors.

An effective and well-documented quality control program can minimize unscheduled scintillation camera downtime. Minimizing unscheduled camera downtime results in significant cost savings. It also improves patient care and maintains patient and referring physician satisfaction with the nuclear medicine service by providing on-time imaging procedures and minimizing patient waiting times.

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By documenting and trending the results of the quality control procedures, significant drifts in camera performance parameters can be detected before the creation of any problem that will cause the camera to be shut down for unscheduled maintenance and cause clinical procedures to be canceled. By detecting operational problems before camera performance falls below the minimum performance levels, service can be scheduled so it interferes minimally with the clinical operation of the camera.

The quality control program also should be incorporated into an institution's or clinic's continuous quality improvement (CQI) and total quality improvement (TQI) programs. In addition, to receive accreditation by the practice audit program of the American College of Nuclear Physicians (ACNP) there must be an established quality control program that meets or exceeds regulatory guidelines. Quality control procedures must be performed to satisfy regulatory and accreditation authorities such as JCAHO, NRC and state regulatory bodies. Finally, documenting that the imaging equipment is performing satisfactorily and within accepted performance limits can be a significant advantage to all parties should the question of image quality arise in a medico-legal issue.

ESTABLISHING SCINTILLATION CAMERA PERFORMANCE CRITERIA

The results from the acceptance test of the scintillation camera serve as the basis for establishing the limits of performance for the quality control program. The acceptance test must be performed before the camera is used clinically. In the case where no acceptance test was performed before clinical use, an equivalent test can be performed to establish baseline values. The methods of performing the various acceptance test procedures are described in the literature (*1–4*) and will be presented in the next three articles in this series.

The initial quality control data and images collected when the camera was first put into clinical service should be used to provide the variation in performance and to set the minimum acceptable performance parameters. The reason for not using the manufacturers' published specifications as the performance guidelines is that in many cases manufacturers publish conservative values and the camera performance may significantly exceed these values. In addition, the cameras that come off the production line vary, in some cases significantly, in their performance specifications. The values obtained from the scintillation camera acceptance testing are critical if a meaningful quality control program is to be established.

A quality control manual must be developed that carefully specifies how and at what frequency each quality control procedure will be performed. The manual should contain the forms needed to record the results of the quality control tests as well as guidance on how to interpret the data and images obtained.

DESIGNING THE QUALITY CONTROL PROGRAM

Quality control procedures are normally divided into those performed on a daily basis, a weekly basis and at other time intervals. There is no universal way of performing quality control nor is there a standard set of procedures for each camera. All quality control procedures must be designed to be compatible with the:

1. Characteristics of the specific scintillation camera;
2. Physical characteristics of the room in which the camera is located;
3. Procedures performed; and
4. Radionuclides imaged.

There are minimum, *mandatory* quality control procedures that must be performed daily and weekly irrespective of how the scintillation camera is used. These procedures must be performed *for each detector.* On a daily basis, these procedures include an energy calibration check, background check and low-count (qualitative) flood-field uniformity test using either ^{99m}Tc or ^{57}Co. A high-count (quantitative) ^{99m}Tc flood-field uniformity test, as well as resolution and linearity checks, should be performed weekly.

Additional quality control procedures must be performed if the scintillation camera is used for SPECT imaging. The frequency of these procedures depends on the performance characteristics and stability of the scintillation camera, procedures performed and radionuclides imaged. These additional, *mandatory* quality control procedures are:

1. High-count (quantitative) flood-field uniformity for radionuclides routinely imaged, other than ^{99m}Tc;
2. Center-of-rotation (COR);
3. SPECT performance phantom imaging; and
4. Pixel calibration.

Each quality control procedure has four components: performance of the procedure; the reference values and images to be used to evaluate the quality control data; the actual evaluation of the quality control data; and a defined set of *actions to be taken* if these quality control data are outside the limits established by the reference values.

The most *critical components* of the quality control program are the daily and weekly review and charting of the quality control data and images and actions to be taken should the results not meet the specified performance limits. These quality control data and images serve no value if they are placed in a binder without being evaluated and no action is taken when the results are outside the established limits.

ACNP PROFICIENCY TESTING PROGRAM

The Proficiency Testing Program (PTP), managed by the ACNP, is the joint effort of the ACNP, the Society of Nuclear Medicine (SNM), the SNM Technologist Section and the College of American Pathologists (*5*). The PTP is designed to evaluate and improve quality in nuclear medicine. This program uses imaging phantoms to assess image acquisition, processing and interpretation of images. Specialized phantoms are

TABLE 1
Sample Weekly and Periodic Quality Control Schedule

Camera type	AM/PM	Monday	Tuesday	Wednesday	Thursday	Friday
Single-detector planar	AM	Quant. ^{99m}Tc flood*		Quant. flood other than ^{99m}Tc**		Linearity and resolution
	PM				Periodic QC procedures†	
Dual-detector planar	AM		Quant. ^{99m}Tc flood*		Linearity and resolution	Quant. flood other than ^{99m}Tc**
	PM		Periodic QC procedures†			
Dual-detector variable-angle SPECT	AM		Quant. flood other than ^{99m}Tc**	Quant. ^{99m}Tc flood*	Linearity and resolution	
	PM	Periodic QC procedures†	COR††	Periodic QC procedures†		
Triple-detector SPECT	AM	Quant. flood other than ^{99m}Tc**			Quant. ^{99m}Tc flood**	Linearity and resolution
	PM	Periodic QC procedures†	COR††	Periodic QC procedures†		

*When quantitative ^{99m}Tc floods are performed, qualitative (low-count) floods are not performed. If integral uniformity based on the quantitative flood exceeds performance limits, a calibration (uniformity correction) table must be run. If integral uniformity is minimally outside performance limits, the calibration table can be run that afternoon and a new quantitative flood must be run the next morning.

**Frequency of performing quantitative floods for radionuclides other than ^{99m}Tc depends on the radionuclides imaged and the stability of the camera. If integral uniformity based on the quantitative flood exceeds performance limits, a calibration (uniformity correction) table must be run. If intergral uniformity is minimally outside performance limits, the calibration table can be run that afternoon and a new quantitative flood must be run the next morning.

†Frequency of periodic quality control procedures depends on how the camera is used and its stability. In some instances, periodic quality control is performed on all cameras during the same afternoon, an example is collimator sensitivity. To save time filling the SPECT phantom with activity, the phantom is imaged on both SPECT cameras on the same afternoon.

††Frequency of performing COR depends on the stability of the camera.

designed for a greater understanding of SPECT imaging, quality control and image perception and are distributed periodically.

The PTP distributes phantoms twice each year. Typically, one phantom simulates a clinical imaging procedure and the other is designed so that the subscriber gains a better understanding of the scintillation camera. A component of both phantom exercises is directed to quality control. Each subscriber receives a critique of how the subscriber performed and their results are compared with everyone who participated in the exercise, along with a discussion of the educational highlights of the exercise. One of the many benefits of participation in this program is that subscribers learn how their quality control programs compare to other laboratories participating in the program.

To learn more about the PTP or to become a subscriber contact: American College of Nuclear Physicians, 4400 Jennifer St., NW, Suite 230, Washington, DC 20015-2113; 202-244-7904.

SCHEDULING QUALITY CONTROL

A quality control schedule must be developed that works with the laboratory's clinical work load and does not require the technologist to work overtime. One or more technologists should start working at least 1 hr before injecting the first patient, assuming the laboratory has more than one technologist. This technologist should perform the daily quality control procedures for the scintillation cameras, thyroid uptake probe and counting systems. If there is no nuclear pharmacist, a technologist also should perform the nuclear pharmacy quality control.

The quality control assignments should be distributed among all of the technologists in rotation to ensure that everyone can perform all of the procedures and technologist time is effectively used. In many instances, during the first 30–60 min after the technologist arrives each morning all the camera rooms are not scheduled. This time can be used to perform the required weekly quality control procedures.

Daily quality control is the first thing done in the morning and before emergency procedures being performed on the weekend. *No patient should be imaged until the daily quality control is completed*, documented and reviewed, by someone other than the technologist who performed the procedure, when possible.

Weekly and periodic quality control procedures should be scheduled during the work week to fit into patient and technologist schedules. Table 1 is a sample schedule for weekly and periodic quality control. If the weekly quantitative ^{99m}Tc floods are to be performed, it is not necessary to run the low-count floods on that camera. However, if the results of the quantitative ^{99m}Tc flood are out of the performance limits, the flood must be repeated or a new uniformity correction table must be collected if the repeated study also is outside the performance limits. If the integral uniformity just exceeds the performance limits, the correction table can be obtained at the end of the day and run overnight or first thing the next morning.

For a laboratory for which the schedule shown in Table 1 would be appropriate, quality control procedures would be run simultaneously on multiple cameras in the morning. For example, on Monday the quantitative ^{99m}Tc flood would be run on the single-detector camera while a quantitative flood for a radionuclide other than ^{99m}Tc is run on the triple-detector system after the daily quality control had been completed. In the afternoon, periodic quality control procedures could be performed on the SPECT cameras, if required. For example, if this were the time to image the SPECT performance phantom, it would be imaged sequentially to save time filling the phantom as well as the cost of the radionuclide.

Another example of saving time preparing radioactive sources, is on Tuesday afternoon, where the COR is scheduled to be run on both SPECT cameras. If there is insufficient time to perform a weekly or periodic quality control procedure at the scheduled time during the week due to patient work load and overtime cannot be approved, schedule scintillation camera time as if the quality control procedure were a patient. Where the technologist does not have enough time to perform the periodic quality control, a qualified hospital physicist or consultant can be retained to perform these procedures. If the technologist does not have the necessary expertise, he or she may be trained.

Preventive and scheduled maintenance should be scheduled during the workweek to fit into patient and technologist schedules. Remember, one of the objectives is to minimize or eliminate unscheduled downtime.

Once a quality control schedule has been established, it is essential to order radionuclides, such as ^{67}Ga, ^{111}In and ^{201}Tl, for the scheduled quality control procedures if the radionuclide is not normally available. When possible, try to use radionuclides that are scheduled for clinical use if the entire vial can be used or a small aliquot can be withdrawn from the multidose vial without reducing the amount of activity required for clinical use. In some cases, for example ^{111}In, it may be possible to save money by obtaining chemical rather than pharmaceutical grade material.

Performing the necessary quality control can be difficult for laboratories with just one or two cameras and a limited technical staff. The administration should be made aware of the time requirements for quality control and how quality control improves patient care and saves money over the long term.

ECONOMICS OF QUALITY CONTROL

Quality control is mandatory and requires institutional support. Capital budget expenditures are required to run a quality control program, as well as an operating budget, camera imaging time and personnel time. The institution can be reimbursed indirectly for quality control if the costs are documented properly and included as part of the cost to perform a nuclear medicine procedure.

The first step is to prepare a capital budget. Table 2 lists some of the items that could be included for the scintillation camera, nuclear pharmacy, counting systems and thyroid uptake probe.

Since most budgets are prepared 4–6 mo before funding is available, base the need for ^{57}Co and other sources on the source activity 16–18 mo hence rather than on the current activity. It is more economical to order the largest ^{57}Co source available based on the counting rate capability of the scintillation camera. If coincidence imaging is performed using a dual-detector scintillation camera, special sources and phantoms are required.

Check which phantoms are available in the laboratory and their condition. Several new phantoms are now available that can save time performing quality control. Some type of SPECT performance or tank phantom should be available in every laboratory. These will be discussed in the third article of this series. Check the nuclear pharmacy, counting instrumentation and thyroid uptake probe to see if additional sources or phantoms will be needed in the next 16–18 mo.

The cost of performing quality control is an integral part of performing a nuclear medicine procedure and should be added

TABLE 2
List of Possible Capital Equipment Required for Quality Control Procedures

For scintillation cameras:
- ^{57}Co sheet source
- Fillable flood phantom
- Resolution and linearity phantom
- SPECT tank phantom
- SPECT performance phantom
- Pixel calibration phantom
- Positron calibration source for coincidence imaging

For the nuclear pharmacy:
- Calibration sources for dose calibrator
- Activity linearity phantom for dose calibrator for quarterly linearity checks

For counting systems and thyroid uptake probes:
- Thyroid phantom
- Calibration sources for thyroid uptake probe and well counter
- Calibration sources for liquid scintillation counter(s)

TABLE 3
Items to be Included in Cost Analysis for Scintillation Camera Quality Control

- Camera time used for quality control procedures
- Technologist time used for quality control procedures
- Capital expenditures purchased for quality control (Table 2)
- Consumable supplies, such as ^{99m}Tc, other radionuclides, syringes, gloves, etc.
- Additional personnel support, such as a qualified hospital physicist or consultant

to the cost of performing a procedure. Table 3 lists the costs to be considered.

Technologist time devoted strictly to quality control should be charged to quality control. For example, if one technologist comes in an hour early and another works 1 hr after procedures are normally scheduled, then 10 hr per wk should be charged to quality control. If, on average, scintillation cameras are scheduled 2 hr per wk for quality control when patients are normally scheduled, then 2 hr of camera time should be charged to quality control.

A pro rata share of the amortized cost of capital equipment purchased to be used for quality control should be charged to quality control. The cost of consumable supplies associated with quality control also should be charged to the quality control budget. In addition, if a consultant or physicist is retained to perform certain portions of quality control, then their fees should be added to the cost of performing quality control.

All of the costs outlined above should be totaled for a year and the number of imaging procedures performed should be divided into this cost to determine the cost of quality control per procedure. This number should be added to the other costs associated with a procedure.

The following reasons, cited at the beginning of this article, should more than justify the expenditure of the time and money for quality control to the administration:

1. Ensure daily that the camera is operating at or near the initial performance level when the camera was installed to provide the best possible diagnostic study and patient care;
2. Minimize unscheduled camera downtime to provide cost savings and improve patient and referring physician satisfaction;
3. Meet the requirements of regulatory and accreditation authorities; and
4. Provide a significant advantage should the question of image quality arise in a medico-legal issue.

ACKNOWLEDGMENT

Permission has been given by Nuclear Associates, Carle Place, NY, publishers of *Scintillation Camera Acceptance Testing and Quality Control–Theory and Practice*, to use material from this publication in this series of articles.

REFERENCES

1. Smith EM. *Scintillation camera acceptance testing and quality control–theory and practice.*, Carle Place, NY: Nuclear Associates; in press.
2. Performance measurements of scintillation cameras. *NEMA standards publication no. NU 1.* Washington, DC: National Electrical Manufacturers Association; 1994.
3. Rotating scintillation camera acceptance testing and quality control. *AAPM report no. 22.* New York: American Institute of Physics; 1987.
4. Murphy PH. Acceptance testing and quality control of gamma cameras, including SPECT. *J Nucl Med* 1987:28:1221–1227.
5. Smith EM, Greenspan BS. The proficiency testing program of the american college of nuclear physicians. *J Nucl Med Technol* 1996;24:342–348.