Appendix I

ARTEFACTS AND TROUBLESHOOTING

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I.1. THE ART OF TROUBLESHOOTING

I.1.1. Basics

Troubleshooting refers to the process of recognizing and identifying the cause of an artefact, a malfunction or a problem in an instrument. The problem could be immediately obvious, for example, the instrument does not work at all or a particular component stops working (such as the computer, the mechanism for whole body scanning or the automatic mechanism for collimator exchange). The malfunction could also be less obvious, and be recognized only by an abnormality in the expected result (such as the pattern formed by a defective photomultiplier tube (PMT) in the gamma camera clinical or quality control (QC) image or an unexpected calibration result in a radionuclide dose calibrator). Such an abnormality is generally referred to as an artefact, in particular, when observed in images.

The malfunctioning of an instrument can occur at any time. It might become evident from a routine QC test. However, it is especially stressful when it occurs during a patient investigation. In such a situation, the first lines of action are to minimize the distress to the patient that a problem has occurred, to remain calm and clear headed, to immediately try to identify the problem and correct it, if possible, and to decide whether the investigation can be continued, either on the same instrument or another similar one, or whether the investigation must be rescheduled. An action flow chart is useful in the decision making process. Such a flow chart is shown in Fig. I.1 for actions following a QC test.

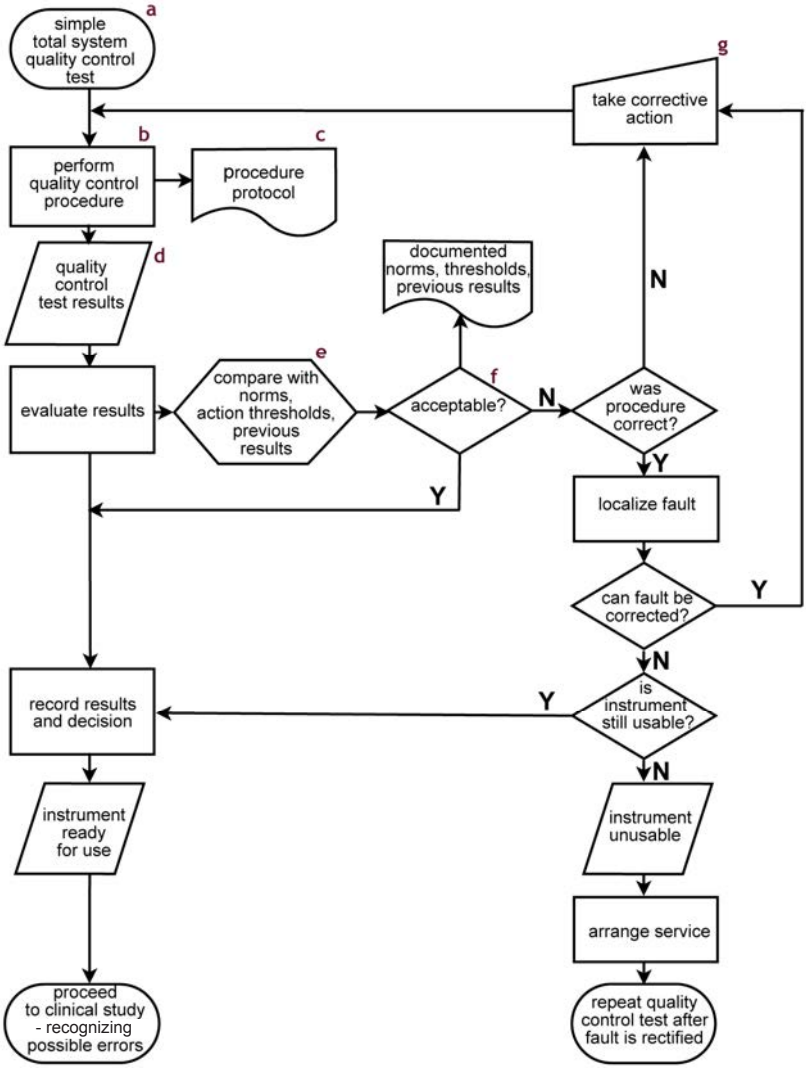


FIG. I.1. Decision tree suggested for performance, evaluation and follow-up of a quality control test. The symbols indicate: a — start or end; b — process to be performed; c — protocol; d — intermediate results; e — checks required; f — decision to be made; g — action taken. Question answer: Y — yes; N — no.

Good communication and teamwork between the personnel of the department are essential, especially when the consequences of an instrument failure or malfunction may involve the action of different disciplines (e.g. taking care of the patient, undertaking first line troubleshooting and problem solving,

decision making if the problem cannot be immediately solved, patient rescheduling).

Available qualified personnel who understand the basic functioning of the instrumentation and the digital environment (e.g. the imaging or measuring instrument, computers, peripherals, network, picture archiving and communication system) are desirable. Up to date protocols for instrumentation function and set-up, instrument calibration, work procedures, clinical studies, QC tests (including action thresholds) and phantom preparation are necessary for creating and maintaining uniform methods within the department. These are an important reference during troubleshooting.

Illustrative examples of artefacts shown in this appendix are restricted to only a few examples. The IAEA Quality Control Atlas for Scintillation Camera Systems is a further valuable resource with many more examples of gamma camera artefacts.

I.1.2. Processes in troubleshooting

Troubleshooting in a clinical environment requires first and foremost immediate action, clear thinking and resources to a network of qualified personnel, in order to minimize down time. The following processes are suggestions to assist when setting up a troubleshooting system within the department:

(a) Identify a qualified person within the department who will have the responsibility for that day to be called upon as first-line support should a problem occur. This person could be the physicist, technologist or technical engineer. They should be called upon immediately when a problem is signalled and be responsible for communication regarding the problem and decisions made.

(b) When a problem is signalled during a patient's nuclear medicine investigation, make every effort to localize the problem as soon as possible. Decide whether the problem can be solved immediately, so that the investigation can be continued (possibly without moving the patient beneath an imaging system), or whether the problem solving will take more time and the patient has to leave the room and return to the waiting room until further decisions have been made.

    (i) Example A: An example of necessary fast action is when the computer or the computer network halts during acquisition of a planar dynamic gamma camera study started immediately after injection of the radiopharmaceutical (e.g. renography). If at all possible, the problem should be solved immediately and the dynamic study continued or restarted. Depending on the type of study, the diagnostic value of the

study may still be salvaged, without requiring the patient to return on another day and receive another radioactive injection. The problem of patching the dynamic study between the first and second parts with missing data may then be tackled afterwards. The nuclear medicine physician should decide whether the interrupted study still has diagnostic value.

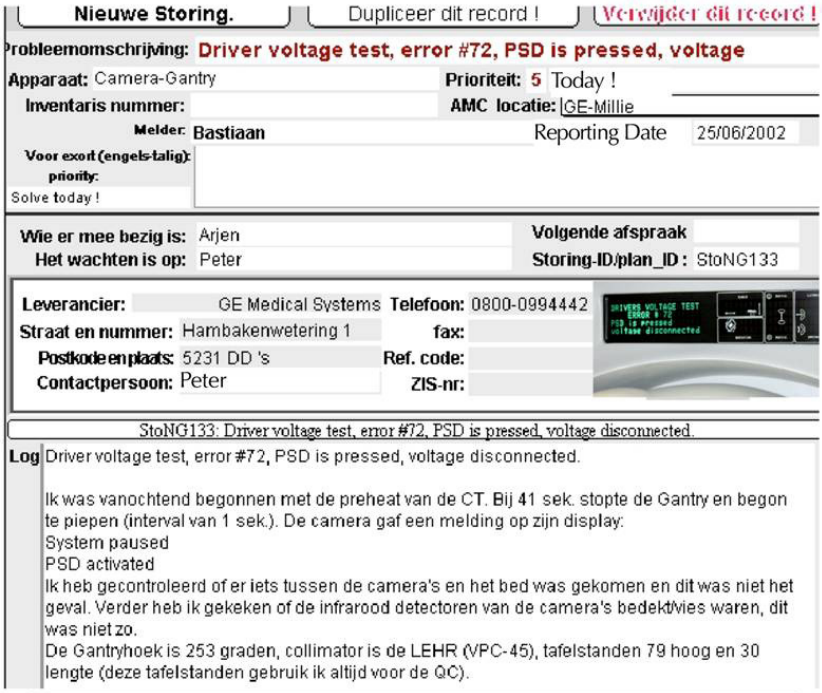
(ii) Example B: A problem during an electrocardiogram (ECG) gated cardiac study may be related to an inappropriate ECG signal to the computer, simply requiring the repositioning of the ECG leads (e.g. a negative R-wave instead of the correct positive R-wave).

Caution: If the data acquisition computer and/or imaging system is to be shut down and restarted, the patient must first be removed from the patient pallet.

(c) If the identity of the problem is not obvious or the problem cannot be solved immediately, a decision must be made as to whether the instrument is totally unusable or usable with limitations until repaired. A partially performed clinical investigation should, if possible and appropriate, be repeated on another similar instrument in the department. This also applies to the other investigations scheduled for that instrument for patients already administered with radioactivity. Any change in instrumentation or protocol must also be noted in the patient record.

Caution: Caution should be exercised regarding the comparative validity of quantitative data when a study is performed on another instrument (e.g. cardiac studies assessing left ventricular ejection fraction).

(d) The problem may need to be solved by an in-house service, a telephone consultation with the service centre of the vendor or by a vendor's service visit, which should be initiated as soon as possible. To assist with localizing the problem, as much information as possible should be documented regarding the circumstances at the time of malfunction, such as other activities being performed (e.g. data processing, data transfer over a computer network, temperature and humidity, power stability, nearby surrounding activities, time of day). A digital photograph of the situation and any error message display on the instrument monitors can be a helpful tool for troubleshooting. An example from a digital log book (created in house using File Maker Pro software) is shown in Fig. I.2.


Nieuwe Storing. | Dupliceer dit record ! | Verwijder dit record !

Probleemomschrijving: Driver voltage test, error #72, PSD is pressed, voltage

Apparaat: Camera-Gantry | Prioriteit: 5 Today !

Inventaris nummer: | AMC locatie: GE-Millie

Melder: Bastiaan | Reporting Date 25/06/2002

Voor export (engels-talig): priority: Solve today !

Wie er mee bezig is: Arjen | Volgende afspraak

Het wachten is op: Peter | Storing-ID/plan_ID : StoNG133

Leverancier: GE Medical Systems | Telefoon: 0800-0994442

Straat en nummer: Hambakenwetering 1 | fax:

Postkode en plaats: 5231 DD 's | Ref. code:

Contactpersoon: Peter | ZIS-nr:

StoNG133: Driver voltage test, error #72, PSD is pressed, voltage disconnected.

Log Driver voltage test, error #72, PSD is pressed, voltage disconnected.

Ik was vanochtend begonnen met de preheat van de CT. Bij 41 sek. stopte de Gantry en begon te piepen (interval van 1 sek.). De camera gaf een melding op zijn display:
System paused
PSD activated
Ik heb gecontroleerd of er iets tussen de camera's en het bed was gekomen en dit was niet het geval. Verder heb ik gekeken of de infrarood detectoren van de camera's bedekt/vies waren, dit was niet zo.
De Gantryhoek is 253 graden, collimator is de LEHR (VPC-45), tafelstanden 79 hoog en 30 lengte (deze tafelstanden gebruik ik altijd voor de QC).

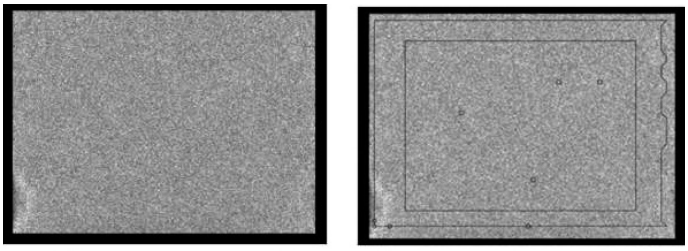
Log Translation: This morning I started with the preheat of the CT. At 41s the Gantry stopped and started to peep (at 1 s intervals). The camera gave a message on its display.
System paused
PSD activated
I checked whether anything had got between the camera heads and bed, but this was not the case. I also checked if the infrared detectors of the camera were covered or dirty, not so. The gantry angle is 253 degrees, collimator is LEHR, bed position 79 high and 30 length (I always use these table positions for the QC).

FIG. I.2. Example of the digital documentation (in Dutch, with log translation) of a gamma camera gantry error. This is one item from the digital database (developed in house) of a troubleshooting log. The error report includes the instrument type, the date of problem report, action priority, room location, name of responsible person, company information, log describing the problem, first-line actions taken and their results. A photograph is included of the gantry error message readout.

(e) Enter all problems and as much related data as possible into the log book specific for the instrument. The solutions should also be documented. A well documented and maintained digital record can be especially useful for assisting with troubleshooting by a search for a previous similar problem or if a repeat problem occurs at a later date. This log book should be started at installation and maintained throughout the lifetime of the instrument, together with preventive maintenance reports and any major modification. Such a log book can also be linked to the QC results and records.

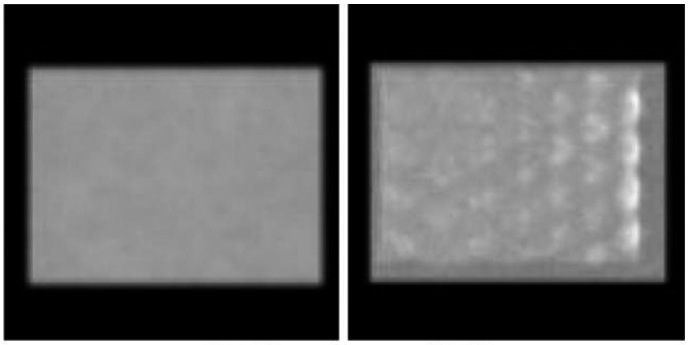
(f) A problem may manifest itself during a routine QC test (such as an artefact from a malfunctioning PMT observed in a routine QC uniformity image). A calibration procedure may fail or show values that are outside the acceptable range. A decision must then immediately be made regarding the acceptability of continuing to use that instrument, whether the instrument can be used with recognized limitations, or whether it must be taken out of use until the problem is solved. This decision making should be communicated with the other responsible staff members. The problem and follow-up actions must be documented in the log book. Two examples of artefacts discovered at the time of routine QC testing of flood-field uniformity are shown in Figs I.3 and I.4.

At the moment of discovering a problem in a QC test, it is uncertain when the malfunction causing the artefact or calibration failure first occurred. The assumption is that it may have occurred at any time between the current and previous QC test. The clinical studies prior to the current QC test should, therefore, be carefully reviewed in order to ascertain when the artefact first occurred, and if the artefact in the clinical images might



NEMA		Uniformity (%)	Specifications (%)
UFOV	Integral	9.53	<3.6
	Differential	6.4	<3.0
CFOV	Integral	3.72	
	Differential	2.79	

FIG. I.3. Weekly system uniformity image (left) from one detector of a dual head gamma camera. The image was obtained with all corrections activated (linearity, energy, uniformity), low energy high resolution collimator, ^{57}Co flood source, symmetric energy window over 122 keV, 256 × 256 matrix, 4 million counts. On the lower left side, there is an irregular hot semicircular area. The National Electrical Manufacturers Association (NEMA) uniformity quantification in the useful field of view (UFOV; right image outer rectangle) confirms that this non-uniformity is outside of specifications. The problem was a loss of gel between the border photomultiplier tube and crystal. Once the gel was replaced, the uniformity was restored. Note: This camera required a service. The defect affected imaging at the edge of the field of view. This detector could, therefore, still be used for imaging within the central field of view (CFOV; right image, inner rectangle) area, for which the NEMA differential uniformity values were satisfactory (planar and whole body imaging, and with caution SPECT imaging).



NEMA		Head 1 Uniformity (%)	Head 2 Uniformity (%)
UFOV	Integral	3.54	20.94
	Differential	2.08	20.00
CFOV	Integral	3.11	15.79
	Differential	2.08	14.64

FIG. I.4. Routine system uniformity images from a dual head gamma camera. The images were obtained with all corrections activated, low energy all-purpose collimators, ^{57}Co flood source, symmetric energy window over 122 keV, 64 × 64 matrix, 16 Mcounts. The uniformity was quantified with the National Electrical Manufacturers Association (NEMA) integral and differential uniformity parameters in both the useful field of view (UFOV) and central field of view (CFOV). The values from detector head 1 were within the expected limits. Detector head 2 shows a gross non-uniformity pattern corresponding to the photomultipliers. This pattern was due to a failure of the electronic correction due to bad electrical contacts of the circuit boards. After re-seating the relevant circuit boards, the problem was solved and uniformity was restored as shown in a follow-up test (not shown here). Note: The non-uniformity of head 2 was extensive and, thus, imaging with this detector had to be suspended until the problem was solved.

have resulted in an incorrect diagnostic report. If it appears that the artefact may have compromised the images and report, a decision must be made whether to recall the patient and redo the study after the problem has been solved, or redo the study on another instrument. An example of an artefact not discovered until the following QC test is shown in Fig. I.5. The nuclear medicine physician should be informed and consulted.

(g) Particular care must be exercised at all times to be alert to artefacts in clinical images, abnormal quantitative readings and data analysis results. An obvious problem is present when an organ uptake measurement is >100%. Constant alertness is an ongoing process, which should be an integral part of daily practice for all members of the nuclear medicine team.

If the same or a very similar abnormal pattern is observed in successive clinical images from different patients, then the abnormal pattern may

be caused by a malfunction in the instrument rather than metabolic dysfunction in the patients. If such a situation is suspected, the problem should first be investigated before further patients are injected and imaged. Troubleshooting may involve not only investigating the instrument, but also checking the radiopharmaceutical quality and integrity of the radioactive administration, etc. It often requires a QC test to assess the situation. An example of uniformity artefacts in lung perfusion studies that were not immediately related to instrument artefacts is shown in Fig. I.6.

The acquired image data for an investigation should always be reviewed carefully before the patient is allowed to leave the department. An artefact or inadequate data may require that the data acquisition be repeated.

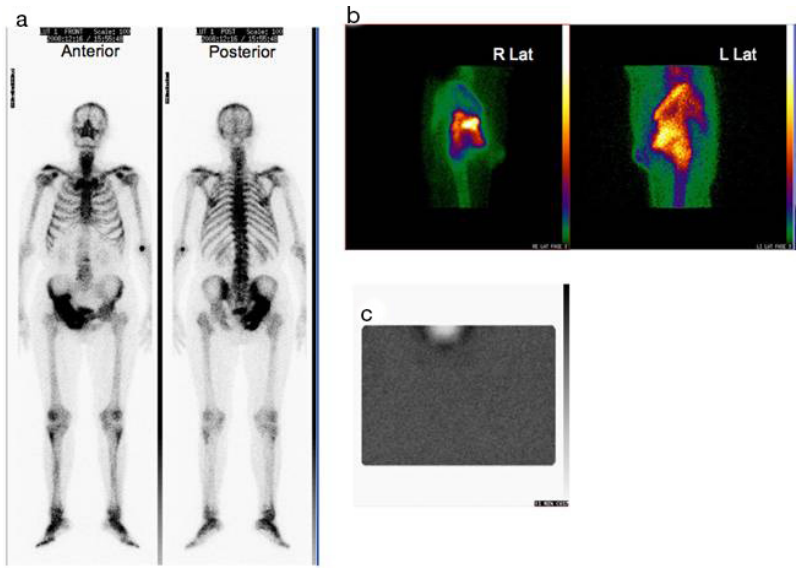


FIG. I.5. A ^{99m}Tc phosphonate bone scan obtained with a dual head gamma camera. (a) Anterior and posterior whole body images. (b) R lateral and L lateral static images of the left knee. (c) Routine system uniformity quality control image of detector 1 taken 2 d later. The photomultiplier tube artefact is at the upper border of the field of view. Note: The bone scan was reported without noticing the malfunctioning photomultiplier tube of detector 1, which was only discovered at the following routine QC test. On review, the effect of the photomultiplier tube artefact was not discernible in the anterior whole body scan made with detector 1 (a), but was visible in the R lateral static of the bone scan using a colour table and high contrast that highlighted low count areas. This example illustrates alertness to an unexpected malfunction. This camera required a service, but could still be used with caution for planar imaging within a limited part of the detector. Owing to the nature of the clinical bone study and the location of the photomultiplier tube artefact, this study was not repeated. The gamma camera required a service.

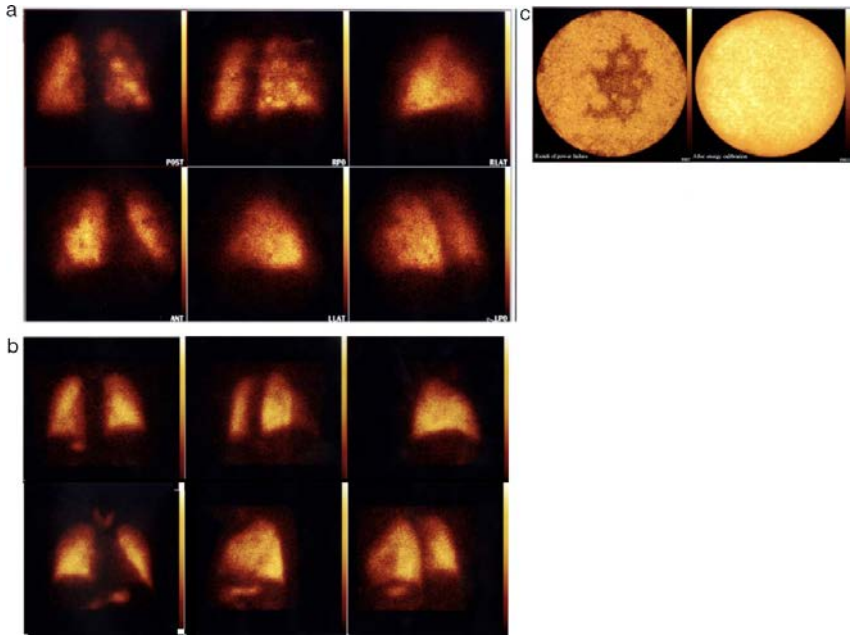


FIG. I.6. A clinical lung perfusion study using ^{99m}Tc macroaggegates. (a) Images of the lungs were obtained with camera 1 (top row images: posterior, right posterior oblique, right lateral; bottom row images: anterior, left lateral, left posterior oblique). The irregular pattern of hot and cold areas was not at first recognized as a camera problem. After two subsequent patients demonstrated the same patchy pattern in their lung perfusion images, the clinicians reviewing the studies questioned the results and troubleshooting was initiated. Quality control of the radiopharmaceutical was acceptable. A uniformity quality control test of the gamma camera was made and this revealed gross non-uniformity ((c) — left image). All patients were recalled and re-imaged on camera 2. (b) Lung perfusion images obtained on camera 2 (with the same image order as in (a)). Camera 1 was retuned, which restored uniformity ((c) — right image). Further investigation revealed that there had been a power disruption during the night. This had corrupted the energy correction values, and explained the reason for the non-uniformity. Note: A routine quality control uniformity test had not been performed at the start of the day's clinical imaging. If this had been done, the problem would have been identified immediately. An uninterruptible power supply was later installed in order to prevent a similar future occurrence. (For more details, see the IAEA Quality Control Atlas for Scintillation Camera Systems.)

(h) After a problem has been solved, the instrument should be tested for correct functioning before being released for clinical use. If computer software or hardware has been changed, reboot and restart the system to ensure that the system works after a power down:

  (i) Be aware of any changes in hardware or software that could affect quantitative results. Validate the results.

(ii) Changes to hardware may require QC testing before the instrument is released for clinical use.

(i) Be aware of an intermittent or repetitive problem. Creative testing and dedicated persistence is required to locate the cause of such a problem. Even after a problem appears to be solved, it may still be present because of instability in a component. For example, this has been the case with electronic grounding, cable connections, cable breaks and a fluctuating power supply. An example of the effect of voltage instability in a single photon emission computed tomography (SPECT) study is shown in Fig. I.7. Continued alertness is always required, as well as repeated QC testing.

I.1.3. Troubleshooting remedies

Various first-line troubleshooting tactics can be useful before resorting to contacting the service. If a service contract is available for an instrument, it should be clear where the responsibilities and limits lie. Some general hints to be considered are given below, although the circumstances are left to the discretion of the troubleshooter. The troubleshooting section of the instruction manual of the instrument should also be consulted.

In the event of failure or instability of an instrument or component (to be carried out by a qualified person or the service engineer):

(a) Check electrical power, circuit breakers, fuses, cables and cable connections, fans;
(b) For accessible batteries, check the level of battery power within the instrument that regulates a specific function;
(c) Check for dust, and cleanliness of sensors and metal contacts.

Computer and network:

(a) If a program halts, exit and restart the program. If this is unsuccessful, shut down and restart the computer. (If restarting the data acquisition computer, make sure that the patient is not on the imaging table.)
(b) For a suspected communications failure between the instrument and the computer, shut down and restart the computer. If this does not solve the problem, shut down both the computer and the instrument, and, after about 30 s, restart the instrument and then the computer. Be careful to follow a correct startup procedure and make sure that the patient is not on the imaging table.
(c) If peripheral equipment (such as a printer) stops functioning or produces an error message, shut down and restart that equipment.

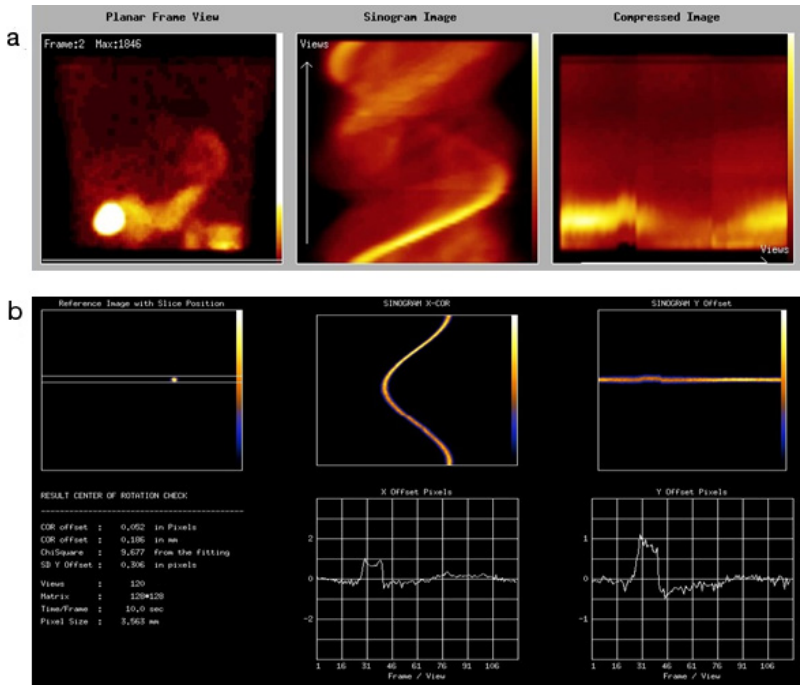


FIG. I.7. (a) Quality control images over the whole field of view of the acquisition data of a SPECT myocardial perfusion study (left — one projection image, middle — sinogram over the whole field of view (X), right — linogram over the whole field of view (Y)). The images were obtained from a 3-detector SPECT system (120° rotation per head, starting with head 1, and a 360° total rotation). The linogram shows an upwards shift in the images from head 1 towards the finish of the 120° rotation (first third of the dataset). In order to clarify the situation, a point source was placed off-axis and imaged with the same data acquisition parameters. (b) In order to test the system, a SPECT acquisition was made of a point source placed off-axis. Quality control images of this acquisition (same image order as above), and their quantitative offset analysis (lower row). Offsets are seen in both X and Y in detector 1 data, identified clearly by the jump in offset in both X and Y on the quantitative analysis. The problem was due to a decrease in voltage to the signal board of detector head 1 at certain projection angles. This was found to be due to instability in the power cable connected to the signal board. The problem was resolved only after replacing the cable. Note: This problem was difficult to locate. A problem was signalled in patient studies by the reporting nuclear medicine physician who observed upwards motion in the quality control review of the patient SPECT data from successive patients. Initially, a corrupted centre of rotation calibration was considered to be the cause. However, the problem repeated itself, and was again recognized on subsequent clinical and point source SPECT acquisitions. It took much persistence from the department to keep on testing the system and several visits by the service engineer before the problem was found. The upwards shift was only seen in one detector head, thus pointing to a problem with the camera and not movement of the patient, which would have been seen in the acquired data of all three heads, at the same time frames.

(d) Check the computer network and communications.
(e) Note: Before instrument re-use, a simple QC check may be necessary to ensure that the instrument is functioning correctly.

Error and artefact in results:

(a) Check the radiopharmaceutical and injection quality, study parameters and instrument settings, and patient positioning before investigating instrument malfunction. Consult the department procedure manuals.
(b) If observed in a QC test, check that the test method was correct.
(c) Initiate appropriate supplementary QC tests, as appropriate.

I.2. IMAGE ARTEFACTS

I.2.1. Recognizing image artefacts and their underlying causes

Pattern recognition is the essential ingredient of interpretation of nuclear medicine images. Thus, recognizing an artefact is also an essential part of pattern recognition. Image artefacts manifest themselves in different ways as a result of different factors. Relating an artefact to the underlying problem causing the artefact is a developing process of understanding the instrument and how it should be used. A particular instrument may show characteristic artefact patterns that repeat and become familiar over time.

An artefact may also be caused by incorrect instrument settings or be patient related. Thus, a daily component of troubleshooting is to review the acquired data before each patient is allowed to leave the department.

Some causes of problems encountered in gamma camera images are given below for different performance parameters. Related images can be found in the IAEA Quality Control Atlas for Scintillation Camera Systems, which is an extensive resource of different types of image artefact that may be encountered in planar, whole body and SPECT imaging modes of a gamma camera system. Examples given in the Atlas include results from QC tests as well as clinical examples.

Problems encountered in gamma camera images for different performance parameters:

(a) Distortion of the energy spectrum photopeak shape, loss of energy resolution: A change may be caused by:
  (i) Poor tuning or energy calibration.
  (ii) Malfunctioning PMT or preamplifier.

(iii) Inadequate or unstable electrical grounding.
(iv) Instability in electrical contact in the detector power supply.
(v) Deteriorating detector material.
(vi) Interference from nearby radionuclides.

(b) Decrease in detector sensitivity: The decrease in count response may be related to:
(i) Incorrect centering of the photopeak window.
(ii) Change in the PMT tuning values or gain values.
(iii) Malfunctioning PMT.
(iv) Deteriorating detector material.

(c) Poor image uniformity of a gamma camera: Image uniformity may be affected by a variety of problems, for example:
(i) Deterioration in detector properties, so that energy and/or linearity corrections no longer correspond.
(ii) Inadequate energy correction for radionuclides other than ^{99m}Tc.
(iii) Offset in centering of the image with respect to the image matrix and corrections.
(iv) Poor tuning of the PMTs.
(v) Malfunctioning or defective PMT(s).
(vi) Loss of optical coupling between PMT and light guide, light guide and crystal surface, or PMT and crystal surface.
(vii) Asymmetrical or erroneous position of the energy window on the photopeak.
(viii) Defects in the collimator (extrinsic uniformity).
(ix) Radioactive contamination on the collimator or detector crystal.
(x) Crystal hydration.
(xi) Broken detector crystal (due to impact or thermal changes).
(xii) Improper QC procedure, including errors due to phantom preparation, e.g. size of a point source, flood source filling, source positioning.

A test of flood field uniformity is the basic most sensitive QC test for the gamma camera. This QC test should be considered as a first troubleshooting QC test when an image artefact is encountered or suspected (see example in Fig. I.8). However, if there is suspicion of a local artefact, relating to a possible PMT malfunction, in the patient's images, it may be the simplest to first repeat an image after moving the patient within the field of view (FOV); if the artefact moves with the patient, the problem is patient oriented; if the artefact remains in the same location, then it is instrument oriented. Further investigations can then be performed (e.g. by making a uniformity QC test). An example of the effect of a defective PMT artefact in static bone scans is shown in Fig. I.9.

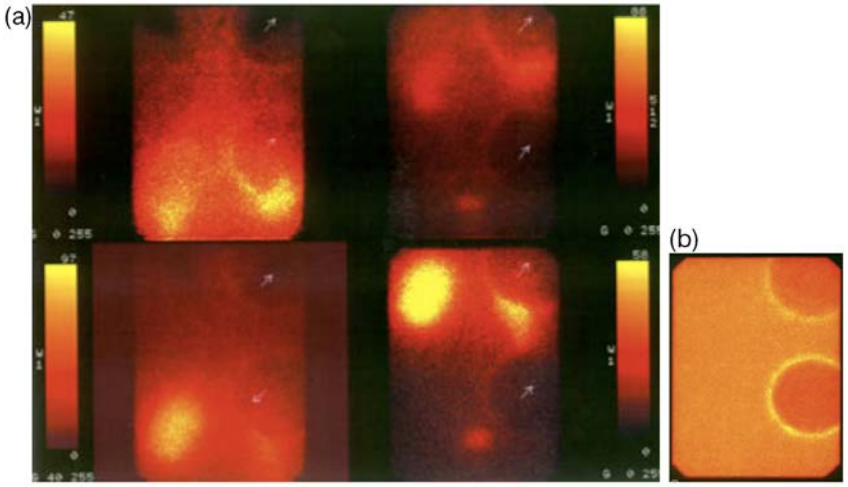


FIG. I.8. (a) A clinical ^{111}In somatostatin receptor study obtained with a single detector gamma camera. The upper and lower abdomen in the anterior view (top two images), and the upper and lower abdomen in the posterior view (bottom two images). Each image of the clinical study showed two large, diffuse, circular colder areas (indicated by arrows). (b) Uniformity image obtained after the clinical study, which shows two large cold areas with a hot border, each due to a defective photomultiplier tube. The non-uniformities in this example were large enough to be recognized in the patient's images at the time of imaging. The images could, therefore, be repeated on another gamma camera system. The problem occurred intermittently, but the fault was never localized. The camera was finally replaced. (Example 2.2.8.6 in the IAEA Quality Control Atlas for Scintillation Camera Systems.)

The appearance of an artefact in the uniformity QC test is dependent on the problem. If the non-uniformity is diffuse or unclear, a sensitive troubleshooting method is to make two further uniformity QC images with asymmetrically positioned energy windows: with the energy window set asymmetrically over the lower half of the photopeak and with the energy window set asymmetrically over the upper half of the photopeak. Non-uniformities are highlighted in such asymmetric images, with cold areas in the one image corresponding to hot areas in the other image. Asymmetric images highlight, for example, poor tuning, problems with an energy correction map, ADC (analogue to digital converter) problems and crystal hydration. Figure I.10 shows an example of the early appearance of extensive non-uniformity patterns in images made with asymmetrical energy windows. These artefacts were attributed by the service engineer to separation of the light pipe from the crystal, which could not be rectified by service and implied replacement of the whole detector. Six months later, these artefacts became evident in the clinically used symmetrical energy

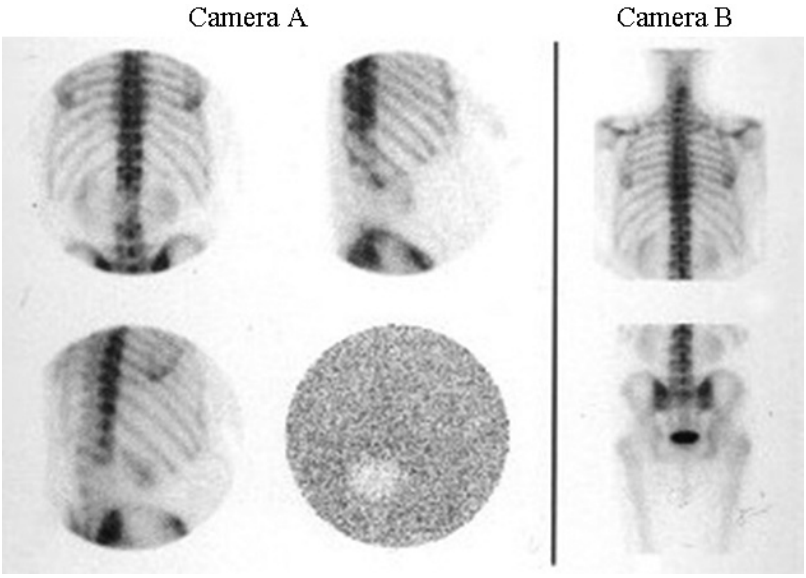


FIG. I.9. Static images of the skeleton after administration of ^{99m}Tc phosphonate. Images obtained on camera A (top left — posterior, top right — right anterior, bottom left — right anterior oblique) show an area of apparent decreased activity in the lower spine that is especially evident in the posterior and right anterior oblique views. As the cold area in the lower spine was unusual, it was not considered to indicate pathology but to be an artefact. The posterior skeleton was, therefore, imaged on camera B, and these images show a normal ^{99m}Tc-phosphonate distribution in the lower spinal column. Subsequently, a uniformity image was obtained on camera A that demonstrated a defective photomultiplier tube that corresponded to the area of decreased activity in the skeleton images. Camera A required servicing before further clinical images were performed. Note: The study was reviewed before the patient left the department. If a second camera had not been available, the patient could have been shifted so as to image the lower skeleton in another part of the camera field of view. (Example 2.2.8.5 in the IAEA Quality Control Atlas for Scintillation Camera Systems.)

window. Early observance of such a situation can assist with initiating a replacement plan. An unusual and unexpected discovery of crystal hydration in a new camera 3 months after installation is shown in Fig. I.11. In this situation, detector replacement was required but this was within the guarantee period. A dramatic example of hydration and poor tuning is shown in Fig. I.12.

(d) Poor image spatial resolution and image contrast: Poor planar image spatial resolution can be caused by:
   (i) Too large a distance between the patient and collimator.
   (ii) Poor linearity corrections of the detector: As visual evaluation of linearity is subjective and difficult to assess, linearity should be

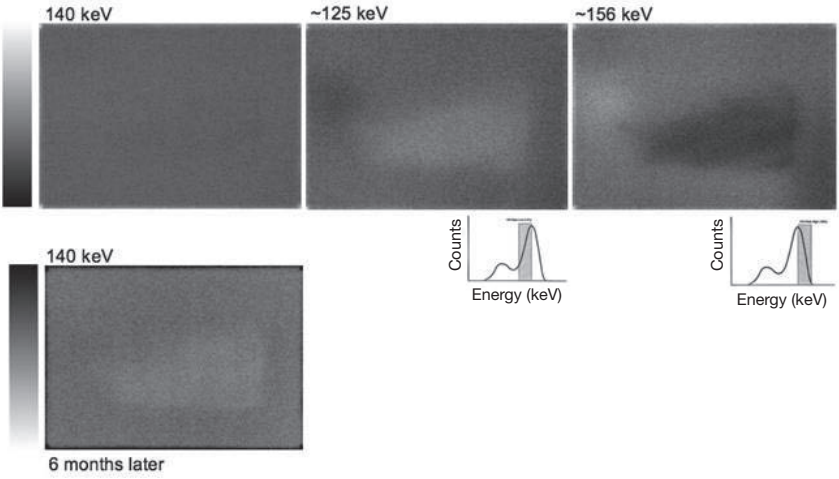


FIG. I.10. Top row: A series of routine intrinsic uniformity images obtained with ^{99m}Tc, uniformity correction turned off, with the energy window set symmetrically (left), asymmetrically low (middle) and asymmetrically high (right) over the photopeak. The bottom image is a repeat intrinsic uniformity image obtained 6 months later on the same gamma camera. Each image was made with 5 Mcounts in a 256 × 256 matrix. The asymmetrical low image shows a large diffuse rectangular hotter central area that corresponds on the asymmetrical high image to a colder central area. Six months later, the same central colder area is now visible on the image obtained with the symmetrical photopeak. This artefact was caused by a separation of the light pipe from the crystal. This problem could not be fixed and the whole detector required replacement. In this particular case, the detector replacement was covered in the service contract. It would otherwise have been a very expensive repair. Note: The colour scale used in these images is reversed between the first images (0–100% counts = black to white) and the image made 6 months later (0–100% counts = white to black). Recording the colour scale together with the images is essential, not only for quality control images but also for clinical images. The colour scale and any colour enhancement should always be taken into consideration when reviewing images.

quantified if software is available. Figure I.13 shows the results of a 6-monthly QC test of spatial resolution and linearity using a slit phantom, where the quantified National Electrical Manufacturers Association linearity values were outside of the specifications in both the X and Y directions, indicating that a new linearity map was necessary.

(iii) Poor multiple energy window registration.

A decrease in image contrast in acquired images may be caused by:

(i) Incorrect position of the energy window and may be an operator error: For example, this can occur if a test or calibration has been performed

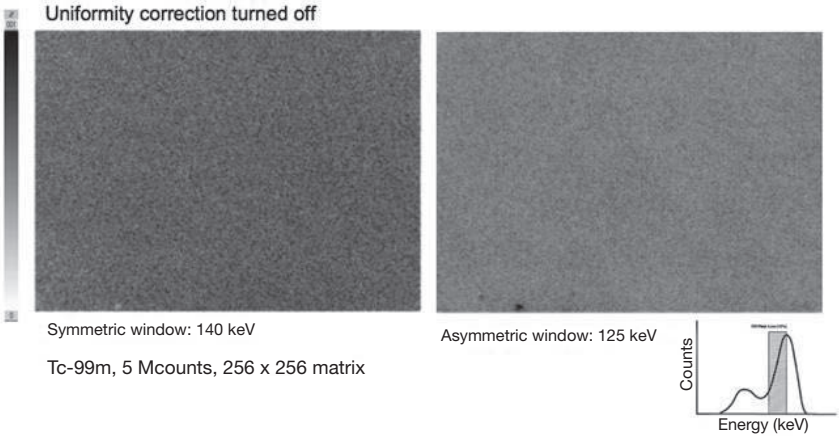


FIG. I.11. Intrinsic uniformity images obtained at 3 months after installation of a new gamma camera. The images were obtained with the uniformity correction turned off (but linearity and energy corrections activated), using a ^{99m}Tc point source, 256 × 256 matrix, 5 Mcounts total. The left image was obtained with the ^{99m}Tc energy window set symmetrically over the photopeak. It shows a suspicious small cold spot on the lower border. In order to investigate this further, the energy window was offset on the lower half of the photopeak (see diagram). The image obtained with this window setting (right) shows a distinct hot spot at the same location as the cold spot on the left images, as well as two other small hot spots close by. This is the result of crystal hydration. The detector can still be used at this moment in time, because the hydrated areas are at the edge of the field of view. However, hydration will continue to develop. The detector required replacement. In this case, the problem was discovered soon after installation within the guarantee period, so that replacement could be made under the guarantee. Note: If this situation is observed in an older gamma camera, a replacement strategy for the detector must be planned. The development of hydration requires close monitoring by weekly or monthly asymmetric uniformity images until replacement takes place.

with a ^{57}Co source, and inadvertently the energy window not been reset to ^{99m}Tc.

(ii) Performing an automatic 'peaking' procedure with the patient as the radioactive source: Owing to the large additional scatter component in the photopeak, the window will automatically adjust too low over the photopeak. The clinical image will, thereby, include unnecessary scatter in the image.

In SPECT, a decrease in resolution and contrast may be related to:

(i) The imaging technique (e.g. excessively large radius of rotation, poor choice of acquisition and reconstruction parameters).

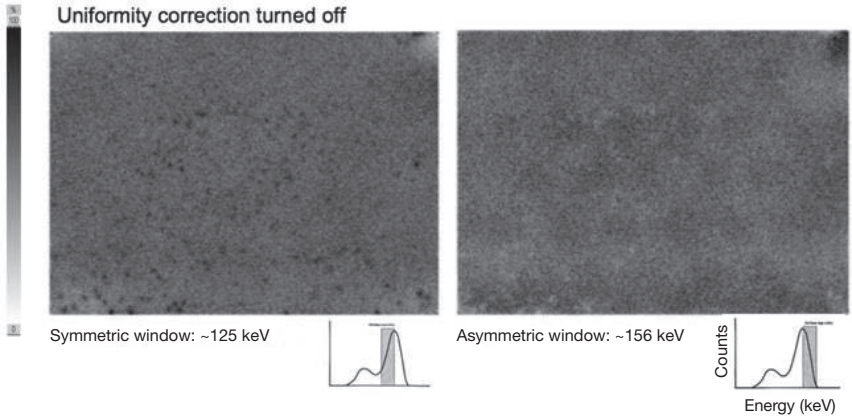


FIG. I.12. Periodic intrinsic uniformity images obtained with ^{99m}Tc, the uniformity correction turned off, and asymmetric energy windows set low (left) and high (right) over the photopeak (each image: 5 Mcounts, 256 × 256 matrix). The images demonstrate extreme crystal hydration over the whole field of view: small hot spots in the low asymmetric window correspond to small cold spots in the high asymmetric window. The asymmetric images also show some poor tuning (especially in the top right corner). The extent of the hydration indicates that this detector requires replacement.

(ii) Inadequate instrument calibration (offset in centre of rotation (in X or Y directions), detector tilt in Y direction, poor alignment of multiple detector heads, inadequate uniformity correction).
(iii) Artefacts in acquired data (missing projections, PMT artefact).
(iv) Artefacts in reconstructed data (e.g. ring artefacts from non-uniformity).

Troubleshooting artefacts observed in SPECT images may simply involve a test SPECT acquisition of a point source placed off-axis (see Fig. I.7) (e.g. for assessing problems of motion between detector heads), or might be more intensive involving a test SPECT acquisition of a cylindrical bottle or a SPECT phantom (e.g. assessing ring artefacts observed in clinical images). The recalibration of the uniformity correction map or the centre of rotation and head alignment (and head alignment in multiple detector systems) may solve the problem. However, a follow-up QC test following recalibration is always required, in order to check that the problem has been solved. Figure I.14 is an example where a recalibration of head alignment was insufficient, and a remaining problem of detector head tilt required a service visit. Further awareness is still required if the problem is an intermittent fault and not solved by recalibration alone (as in the situation of the example in Fig. I.7).

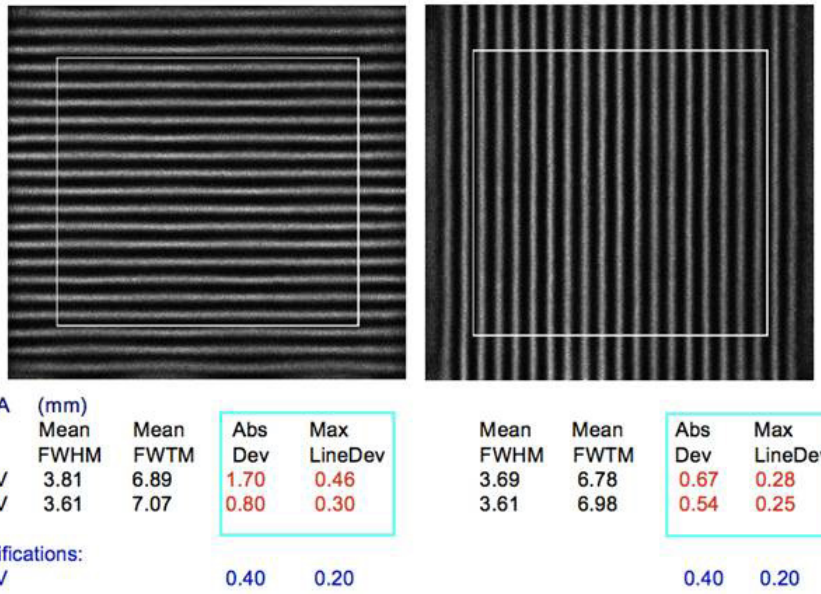


FIG. I.13. Routine 6-monthly quality control test of intrinsic linearity and spatial resolution of a small field of view gamma camera, using a slit phantom with 1 cm spacing between slits, ^{99m}Tc point source, 1024 × 1024 matrix (pixel size: 0.29 mm). The acquired images were quantified within the indicated rectangles. The spatial resolution was within specification. However, linearity (absolute deviation: Abs Dev; maximum line deviation: Max LineDev) was out of specifications in both the X and Y directions. The linearity correction maps needed recalibration. NEMA: National Electrical Manufacturers Association; FWHM: full width at half maximum; FWTM: full width at tenth maximum; UFOV: useful field of view; CFOV: central field of view.

(e) Clinical investigations: A review of data acquired is essential before processing and quantification:

(i) For SPECT data, a cine, sinogram and linogram can suffice to review the clinical data for patient movement, missing projections, instability (an artefact that appears in only some projections) and inadequate continuity of data from multiple detectors. If the review reveals such errors, then the study may need to be repeated.

Note that an artefact due to patient movement will be imaged by all detectors at the same time, so that the movement artefact will repeat. If a 'movement' artefact appears only in one detector of a multiple detector system, then the problem is probably due to the instrument (as an example, see Fig. I.7).

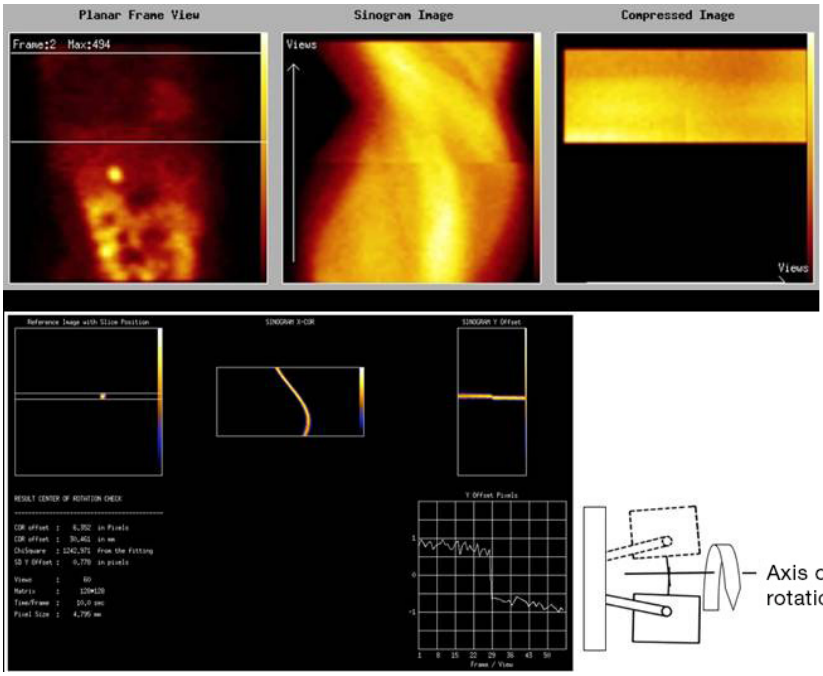


FIG. I.14. Top: Quality control images of a SPECT myocardial perfusion study using a dual head gamma camera in a 90° configuration, 180° rotation (90° per head), 128 × 128 matrix, 4.8 mm pixel size. Images: left — one projection of the acquired data, middle — sinogram (X) of a profile over the myocardium (shown in the left image), right — linogram (Y) for the same profile. There is a discontinuity between detector 1 and 2 visible on both the sinogram and linogram. Bottom: After recalibration of the centre of rotation and head alignment (first trouble-shooting technique applied), a test acquisition was made of a ^{99m}Tc point source placed off-axis (left image projection). The sinogram (middle) shows no discontinuity, whereas the linogram (right) shows both discontinuity and slope in the data — particularly evident in the quantified offset graph. The problem was a detector head tilt in both heads, which required a service.

I.3. MINIMIZING PROBLEMS

Problems can occur at any time, but taking appropriate precautions can minimize the likelihood.

I.3.1. Siting and room preparation

The location of an instrument and good preparation prior to installation are vital first steps. Particular care is needed to choose a location suitable for the

specific instrument in order to avoid interference from X rays, magnetic fields (magnetic resonance imaging), radiotherapy machines, radioactive sources from the radiopharmacy, injection room or radioactive patients (such as from radionuclide therapy or positron emission tomography (PET)).

Considerations for room preparation should include the following:

(a) Necessary wall shielding from extraneous radiation and magnetic fields.
(b) Floor weight support and floor levelling.
(c) Continuous stable electrical power supply: Consider connecting the instrument to an emergency power supply and installing an uninterruptible power supply (UPS) (see Sections 7.6.2 and I.3.2). Consider the electrical conditioning, grounding and safety.
(d) Sufficient strategically placed power outlets for peripherals.
(e) Lighting and switches (to exclude electrical interference with equipment).
(f) Window placement with respect to the instrument position to avoid drafts and influence from direct sunlight. (Particular care is needed for the gamma camera with respect to exposing the crystal to a sudden temperature change such as might happen during collimator change and intrinsic QC measurements.)
(g) Stable air conditioning with respect to temperature (maximum, minimum, fluctuating temperatures) and humidity (non-condensing): Consideration should be given to these aspects not only during working hours, but also outside of working hours, including at weekends. A major hazard to a gamma camera crystal is a rapid change of temperature: a rule of thumb is that the temperature should not change more than 4ºC over 1 h.
(h) Dust free environment: It is generally not possible to achieve a dust free environment in a hospital. However, maximizing a dust free environment should be aimed for, especially for the computers and picture archiving and communication system.
(i) Positioning of the instrument within the room to minimize interference from external radioactive sources.

I.3.2. Electrical power conditioning

The stability and correct voltage level of the electrical supply is crucial to reducing the likelihood of obtaining an instrument malfunction. This may be achieved by use of a surge protector, a constant voltage transformer or a UPS (battery backup), the choice being dependent on the type of equipment and local environmental requirements.

The UPS is essential where power failures or major power dips and surges occur, in order to avoid the disastrous failure of instruments and computers and

the breakdown of components. Even if the instrument's regular power supply is connected to an emergency power supply, the interval between failure of the regular power supply and the initiation of the emergency power supply may produce a power dip sufficient for the instrument to halt or a circuit breaker to switch off (particularly disruptive when occurring during a patient study; see also Fig. I.6).

The investment for a UPS must be considered when requisitioning and purchasing the instrument. A UPS should be connected to all sensitive instruments that are required for daily routine patient care. The UPS specification is dependent on the instrument's power requirement and the local power situation. The UPS may be needed to ensure that, in the event of a power failure during working hours, the instrument can be manually shut down in the correct way. The UPS may be needed only to bridge the gap between a regular power failure and the switch to the emergency power supply.

The electrical conditioning includes appropriate grounding, and shielding of cables, especially for signal cables and data transmission cables.

Electrostatic disturbances can be minimized by adequate humidity control (air conditioners), and antistatic work surfaces and floor covering.

I.3.3. Regular preventive maintenance

Regular preventive maintenance and a service contract can help not only to minimize the chance of an unexpected problem occurring, but also to minimize the down time when a problem has occurred. The expense of a service contract can be considered as an insurance policy. A service contract should ensure fast response and priority access to spare parts. The service may include remote computer login and access. In-house access to trained personnel is also essential for first-line troubleshooting of electrical failures, computer and network failures, and mechanical failures. Without any access to appropriate support, a problem can take a considerable time to be solved, add extra expenses, and become a major obstacle to high quality and continuous patient care.

I.3.4. Acceptance testing and routine quality control testing

Thorough and careful acceptance testing is the first step towards ensuring that an instrument is performing according to specifications and as expected for clinical use. Any problems or suspected problems encountered at this early stage require instant rectification as the instrument is still under the guarantee period (see the example of crystal hydration observed at 3 months in Fig. I.11). Replacement of any defective component must be initiated. The collimator is particularly sensitive to damage from transport and must be tested carefully at

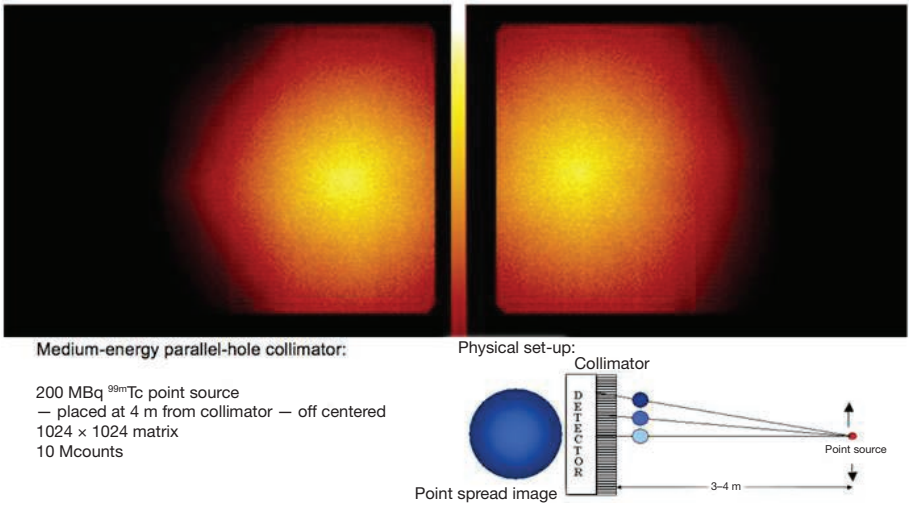


FIG. I.15. Acceptance testing of a medium energy collimator using a distant point source of ^{99m}Tc (acquisition parameters given above). The point source was positioned first to image the right part (left image) and then the left part of the collimator (right image). There are vertical discontinuities evident, probably from the manufacturing process. This collimator was replaced within the guarantee period. Note: This is a sensitive method for testing a collimator for hole angulation problems and for any suspected damage. A large distance between the source and collimator is essential. This test supplements a high count system uniformity test.

acceptance and at any time when damage is observed or suspected. An example of a defective collimator discovered at acceptance testing is shown in Fig. I.15.

Routine QC tests are performed on the gamma camera and SPECT system in order to assess performance of the instrument at a specific moment in time. They are intended to reassure the user that performance up to that moment is satisfactory. Monitoring the results of successive QC tests can indicate a stable functioning condition, deterioration or an impending problem. A database of results is recommended. The visual as well as quantitative results must always be reviewed together. Figure I.16 illustrates a situation in which the quantitative uniformity value appears to be acceptable, whereas the image shows there is a PMT problem. Routine QC tests are valuable in troubleshooting, and should neither be underestimated nor neglected. The results of QC tests can highlight the underlying problems.

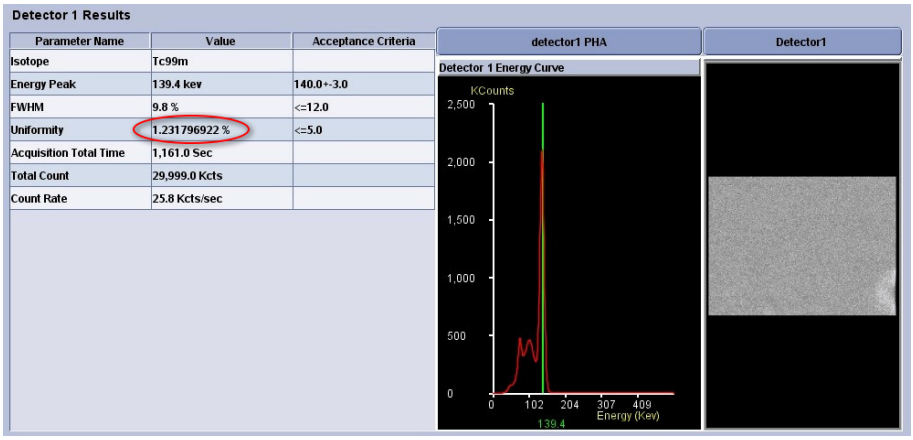


FIG. I.16. Routine intrinsic uniformity image with quantification. The image was obtained with a ^{99m}Tc point source, symmetrical energy window over 140 keV, 30 Mcounts. The image shows a hot semicircular area in the lower right field of view. The quantification indicates that the uniformity is acceptable. However, not indicated in the results, the uniformity calculation refers only to the central field of view. The artefact was due to a malfunctioning photomultiplier tube. Note: This camera required a service but could continue to be used with caution because of the lateral location of the defect. This example illustrates that it is essential to review together both image and quantification, and to understand the parameters provided in the results.

I.4. IMAGE ARTEFACTS IN PET/CT

PET and combined PET/computed tomography (CT) require users to develop skills in recognizing a range of artefacts which are quite distinct from those which may be seen in SPECT or SPECT/CT. PET and SPECT reconstruction do have aspects in common, resulting in analogous methods of recognition; however, the artefacts themselves may appear quite different due to intrinsically different modes of acquisition. PET scanners usually employ a fixed full-ring detection system, unlike SPECT which has a rotating gamma camera, thus eliminating the need for a centre of rotation correction and its associated artefacts. In a typical PET system, a ring of detectors surrounds the patient, each of which simultaneously and independently acquires data. In addition, there is no collimator used in 3-D PET, leading to a vast increase in scanner sensitivity such that acquisition times are generally shorter and whole body scans are the norm. The use of very many individual detectors in PET implies that cameras with minor defects can be tolerated unlike in SPECT, where a defect has a variable impact depending on its location (greater impact towards the centre of the FOV) but may still be usable if the defect is towards the edge of the FOV.

PET is most often performed with an accompanying CT scan, usually acquired using a hybrid scanner where the CT component can be used diagnostically. This requires bed translation between the PET and CT scanners, whereas some SPECT/CT scanners use an integrated low-end CT scanner that is co-located with the gamma camera detectors within the gantry and does not require any bed translation.

The medical physicist needs to be able to derive what the underlying problem is from the artefact, whether it is of a hardware or software nature. This task can be difficult owing to the very diverse way in which scanner problems can present themselves as artefacts. It is useful to classify PET/CT artefacts into the following categories: tomographic artefacts, attenuation correction (AC) artefacts, co-registration artefacts and movement artefacts. Explanations and examples of each are given below, and IAEA Human Health Series No. 27 provides further information and examples.

I.4.1. Tomographic artefacts

Tomographic artefacts are those which appear when some fundamental aspect of the tomographic system performs below specification or else fails entirely. Problems in the tomograph lead to systematic image abnormalities that occur regardless of the type of acquisition being performed. One such abnormality is due to incorrect normalization. Figure I.17 demonstrates an artefact that was created when the normalization of the tomograph had been corrupted. Normalization corrects for the sensitivity difference between different lines of response (LORs). Sensitivity differences are caused by both a geometric distortion, which needs to be measured only once at the factory, and by detector efficiency variations that can change with time and must be periodically recalibrated. Normalization errors occur in the projection space and appear as circular defects in the transaxial reconstructed space. In the example of Fig. I.17(a), the artefact is seen to be repeated in each bed position of the whole body acquisition, indicating that there was a problem with the tomograph itself.

The daily quality assurance routine is a good way to detect unexpected sudden normalization errors. Some quality assurance routines involve scanning a cylindrical phantom filled uniformly with radioactivity (e.g. ^{68}Ge, ^{18}F). Such a cylindrical phantom is designed to be large enough to cover many of the potential LORs in the system. The artefacts due to normalization errors seen in the clinical images of Fig. I.17(a) were clearly visible in the uniformity QC image, as shown in Fig. I.17(b).

Geometry is often the key in diagnosing tomographic artefacts, as can be seen in Fig. I.18, where there has been failure of a detector block leading to a distinctive pattern in the sinogram of the QC uniformity image. Detector block

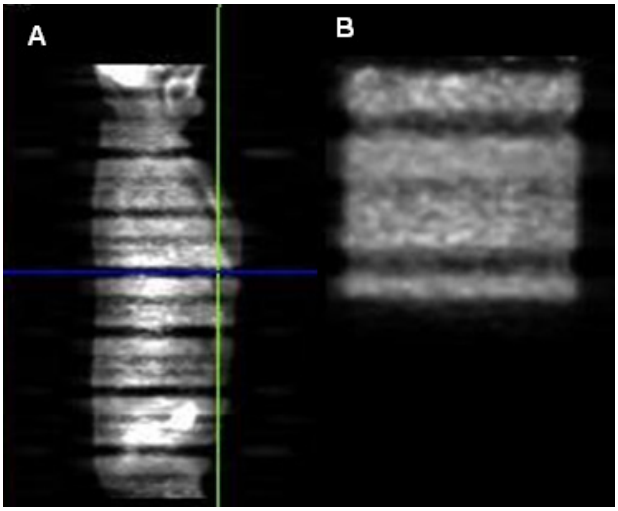


FIG. I.17. (a) Clinical whole body images obtained on a PET system in which the normalization correction was corrupted, but not known at the time. The sagittal view shows a pattern of repetitive cold horizontal stripes at consistent locations within each of the bed positions. The periodic nature of the artefact is a sign that the problem is associated with the system rather than this particular patient or acquisition. (b) Sagittal view of a uniformity quality control check of the PET system acquired using a uniformly filled cylindrical phantom. The image shows cold stripes indicative of errors in the normalization table. This quality control image was obtained after the clinical images revealed the artefacts shown in (a). The quality control image shows several cold streaks which indicate that the problem is most likely a corrupted normalization file. Normalization was recalibrated before further patient acquisitions were performed. (Courtesy of the Department of Nuclear Medicine, Monte Tabor São Rafael, Brazil.)

failure may not contraindicate the clinical use of a PET system since modern scanners have many detectors and the absence of one block may have little statistical impact. Examination of the sinogram (also in clinical images) is a good way to test for block failure, as it appears as a distinctive diagonal streak on the sinogram.

I.4.2. Attenuation correction artefacts

AC artefacts occur when the CT AC algorithm leads to a hot or cold spot in the attenuation corrected reconstructed data. AC effectively increases the counts in each voxel in proportion to the total attenuation along all LORs that pass through that voxel. When the CT image shows a highly attenuating material in a group of voxels, then the total counts along all lines of response that pass through those voxels are increased, and the group of voxels appears hot. This is

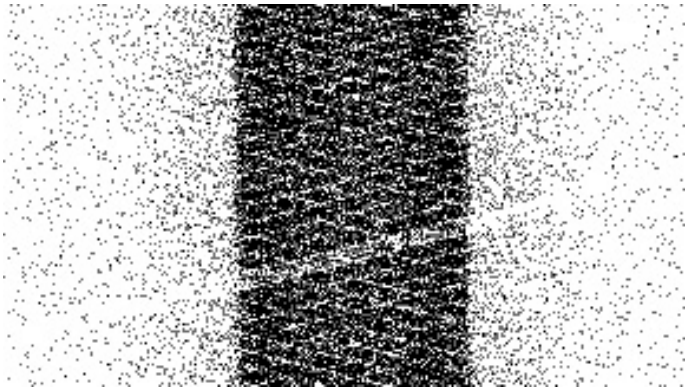


FIG. I.18. Sinogram from a PET system that has a detector block failure. The diagonal streak that is clearly visible is the pattern created when one detector block has failed and causes many lines of response to be zero. The failed detector block creates several blank lines of response at every projection angle at incremental radial positions and the result is a diagonal streak. With only one streak visible, and the fact that the streak is several pixels wide, it would be appropriate to assume that a whole detector block has failed. The noticeable width in the streak occurs because each detector block contains many individual detector elements. Multiple simultaneous detector block failure is unlikely in a system which has regular quality assurance tests. This system is still acceptable for clinical use because there are many detector blocks in a PET system and the loss of one block results in a drop in sensitivity of only ~0.5%.

particularly noticeable where the patient has metal implants or has taken contrast media. The attenuation of metal and contrast at the CT energy does not relate linearly to the attenuation at annihilation photon energy. In this situation, the AC is overestimated and a hot spot appears erroneously at the point where the metal or contrast media is found. Figure I.19 demonstrates a contrast artefact leading to a hot spot that appears cold on the corresponding non-AC PET image. The non-AC images are often a key component in recognizing metal or contrast based artefacts, but the presence of streaks in the CT image is also a warning sign. The non-AC images should always be reviewed whenever any dubious finding is suspected in the AC images.

Another AC artefact is due to truncation, where the CT and PET FOVs are not the same size, so that parts of the anatomy outside the CT FOV are not corrected for by the AC algorithm. This often occurs when the patient's arms (which are raised above the head during the acquisition) are outside the CT FOV and a cold stripe appears across the patient's head in the AC images. In Fig. I.20, a cold stripe is prominent in the AC images but not visible in the non-AC images. Some PET/CT systems include software that can reconstruct the truncated CT data to increase the FOV and, thereby, reduce the severity of the artefact.

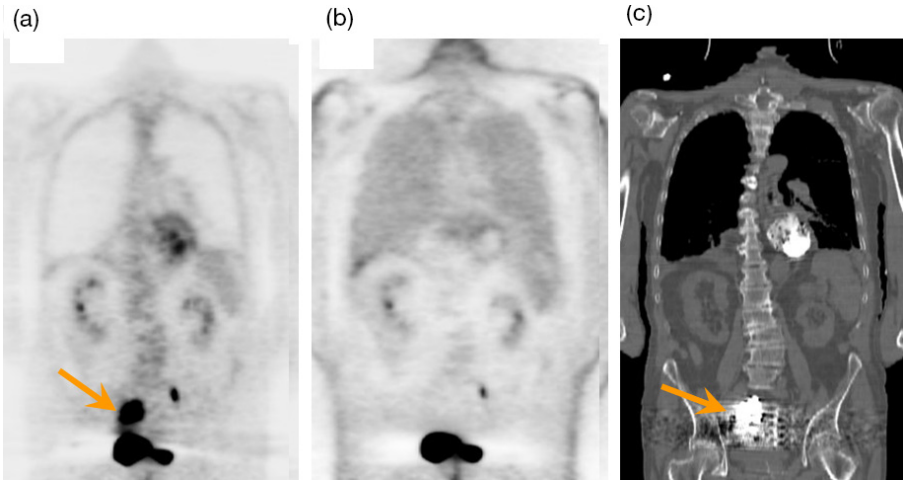


FIG. I.19. (a) CT attenuation corrected image of a patient showing a focal hot spot (indicated by the arrow). (b) Non-attenuation corrected image. The hot spot is no longer visible. (c) CT image showing a high density artefact from barium contrast pooled in the bowel. The artefact appears to be a region of high attenuation and the reconstruction algorithm overcompensates and creates a false hot spot. On the non-attenuation corrected image, the hot spot is entirely gone. These high density material artefacts are very common and the user should always examine the non-attenuation corrected image to check for the presence of such artefacts. Clues can also be found by examination of the corresponding location on the CT. (Courtesy of the Department of Nuclear Medicine, Memorial Sloane Kettering Cancer Center, New York.)

I.4.3. Co-registration and motion artefacts

Problems in co-registration in PET/CT are common and can be due to a system error or caused by movement of the patient. The system must be tested and recalibrated periodically, whereby a transform matrix is created to co-register the PET and CT data. Small errors in co-registration can often be seen in the head where the brain does not correctly fit inside the skull. Errors in the co-registration can occur either suddenly or gradually and can be a sign that there is a problem with the mechanism that controls the bed motion. Regular QC is required.

Alignment errors originating from patient motion are problematic and can have an effect on the medical interpretation of the image. The effect of an alignment error is demonstrated in Fig. I.21, where the patient's head has moved during data acquisition causing a misalignment between the PET and CT data. In the attenuation corrected images, the cortical uptake appears asymmetrical, but it can be seen from the fused PET and CT image that this was caused by a mis-registration error.

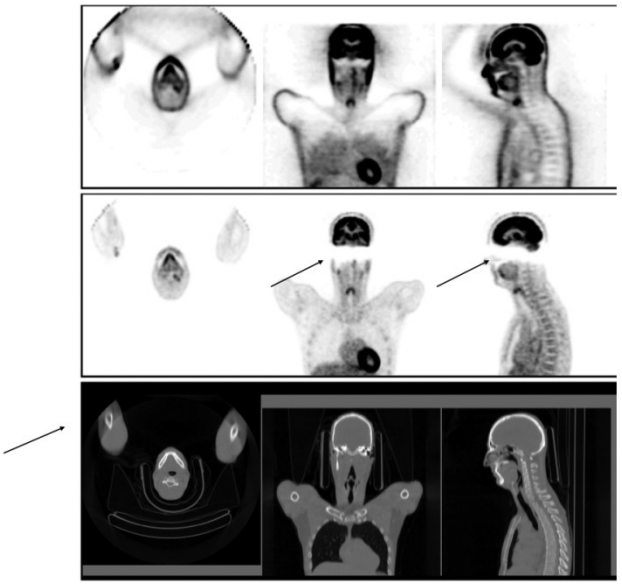


FIG. I.20. Clinical [^{18}F]-fluorodeoxyglucose images of the head and thorax from a PET/CT system. Top row: non-attenuation and scatter corrected PET images; middle row: the corresponding slices with attenuation and scatter correction; bottom row: CT images. The patient's arms have been truncated and extend beyond the CT field of view (arrow, bottom row). Although the truncation was relatively localized, using these CT data to correct for attenuation and scatter produced more extensive errors. This is shown by the cold band in corrected coronal and sagittal images of the head (arrows, middle row). The extent of this artefact may be due to an error in scaling of the scatter correction. The non-attenuation corrected images do not show the cold band. This example also demonstrates the essential value of comparing images with and without attenuation correction. (Courtesy of R. Boellaard, Department of Nuclear Medicine and PET Research, VU University Medical Centre, Amsterdam, Netherlands.)

Patient motion artefacts can be easily missed and lead to an incorrect diagnosis. In whole body PET scans, it is possible for the patient to move during the acquisition so that some part of the anatomy is accurately registered between PET and CT, while in another part of the anatomy the registration is poor. When not noticed by the operator and the reporting doctor, these artefacts can be misinterpreted as pathological uptake or be mistaken for a problem with the system. An example of this is shown in Fig. I.22, where the patient moved towards the end of the scan, causing an erroneous hot spot to appear in the wrong place.

Another movement artefact often seen is due to respiratory motion. PET images are acquired over many respiratory cycles, such that the final image is an average activity distribution across the respiratory cycle. The CT images are

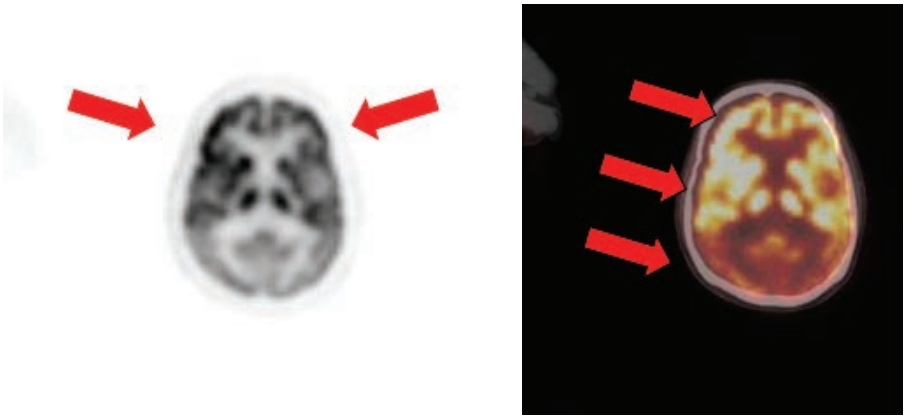


FIG. I.21. Apparent asymmetrical uptake of ^{18}F-fluorodeoxyglucose in the brain (left) caused by the slight misalignment of the PET and CT images (right). The non-attenuation corrected image did not show this asymmetry. These images form part of a whole body acquisition, which commenced at the thigh and moved up towards the head, which was the last part of the scan. Movement in the lower part of the body was not evident.

acquired far more quickly and, thus, demonstrate blurring over only a small component of the respiratory cycle. This can create a mis-registration and blurring in the AC PET images at the boundary of lung and liver. This kind of artefact can have significant clinical implications when a tumour is found near the border between the lungs and the liver. Figure I.23 shows an example where a lesion in the liver is incorrectly located in the lungs. This is due to the CT being acquired during full inspiration (the patient has taken a deep breath, pushing the diaphragm down and displacing the liver caudally), as opposed to the PET which is time averaged over regular tidal breathing, resulting in a severe mis-registration between the functional and anatomical location of the lesion. Conversely, Fig. I.24 shows an example where a tumour is incorrectly located in the liver due to a respiratory motion artefact.

Respiratory motion artefacts can also be seen in the CT image itself where the liver is not correctly rendered during reconstruction of the CT data because the patient is breathing during acquisition. This can be seen in Fig. I.25 where there is a characteristic artefact repeated along the axis of motion, leading to unclear definition of organ boundaries.

I.5. IMPORTANCE OF REGULAR QUALITY CONTROL

Regular QC procedures vary between scanner vendors; however, daily QC often requires checking the gantry status (voltages, temperatures, etc.) and

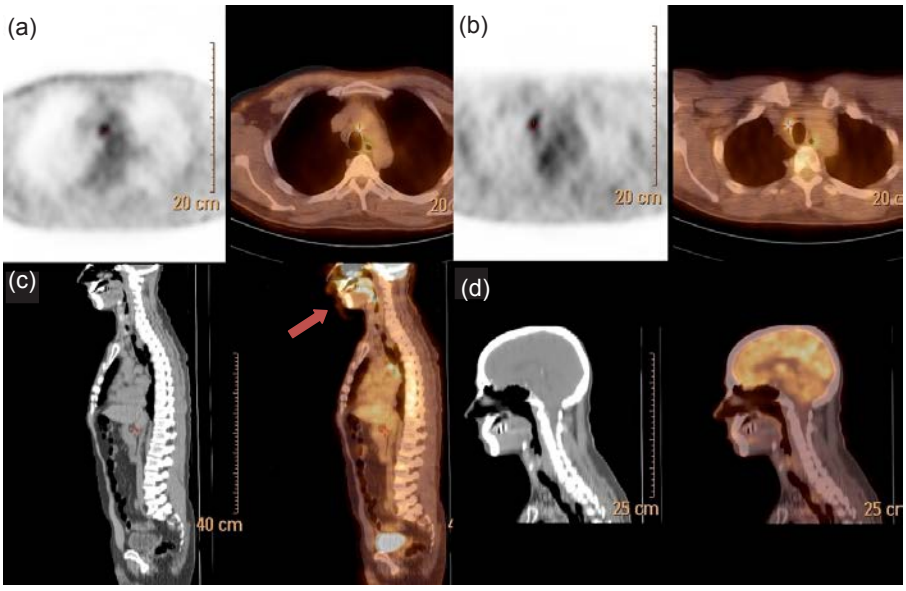


FIG. I.22. (a) A whole body PET/CT scan shows a point of focal uptake in the upper torso. (b) Separate head and neck acquisition of the same patient — the focal hot spot seems to have moved to a different location. (c) Whole body fused images show good registration between PET and CT in the bladder, spine and heart, and so it was assumed that the images were correctly registered; however, closer inspection of the head shows a clear mis-registration (indicated by the red arrow). (d) Fusion between PET and CT in the separate head and neck view shows good registration. The operator did not closely inspect the head and neck portion of the whole body view since there was a separate head and neck acquisition; however, the patient moved during the scan, probably by rotating the head. Had there not been a separate head and neck view, the doctor would have reported the focal uptake as metastatic cancer. This image was reported to the staff physicist as a problem with the system; however, it was in fact operator related. (Courtesy of the Nuclear Medicine Department, St. Vincent's Hospital, Darlinghurst, Australia.)

generation of the normalization from a high count emission image to ensure image quality (including checking a number of parameters, such as block noise and efficiency, scatter ratio, time alignment, etc.). The system vendor should provide a daily QC package that automates all of the above requirements so that QC can be performed quickly by the operator before the commencement of scanning. The daily QC procedure should produce a report indicating any unsatisfactory results which require further attention and allow for systematic monitoring of the scanner.

The characteristics of PET/CT systems allow for quantitative imaging that can display the absolute concentration of tracer in the subject. The ramification

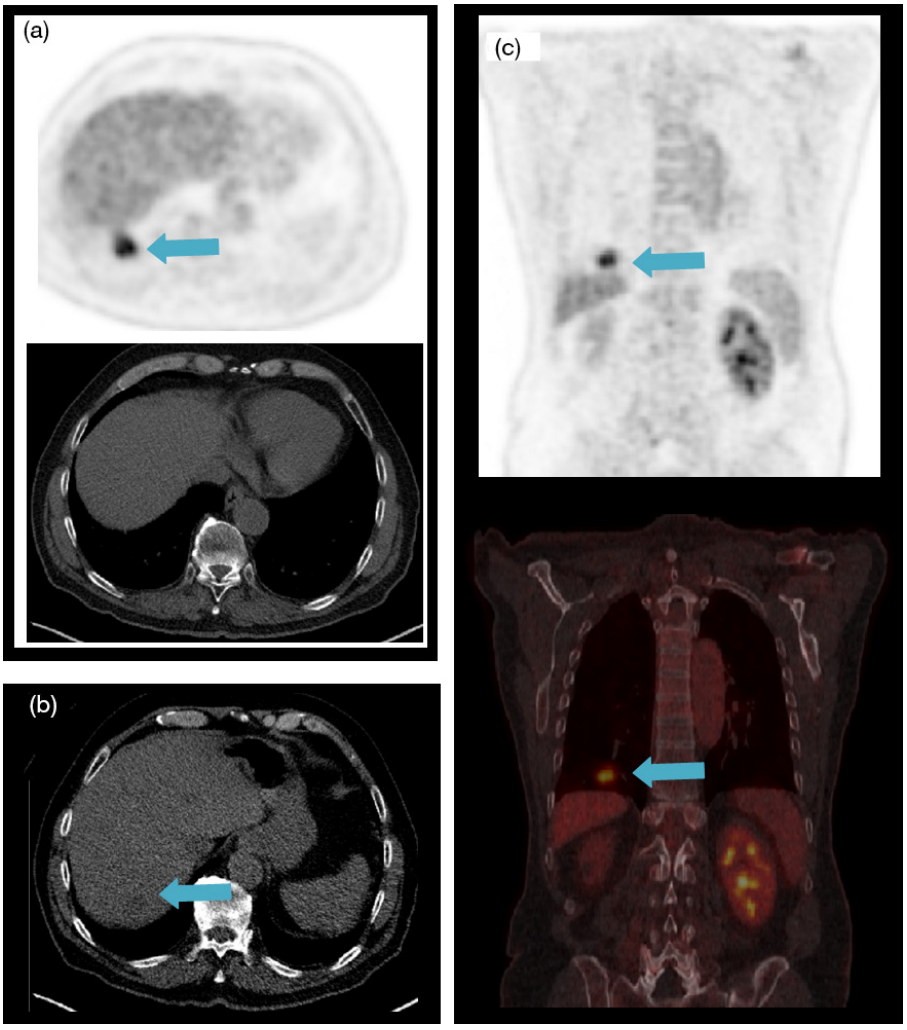


FIG. I.23. (a) Transaxial PET and CT images show a focal lesion, which appears to be in the lung. (b) The CT image shows the same lesion appearing to be in the liver. (c) Coronal view of PET and fused PET/CT where the lesion appears largely displaced from the liver. This problem occurs because the CT acquisition is very brief and captures the liver at one point in the respiratory cycle (in this case, full inspiration such that the diaphragm has displaced the liver caudally), while the PET acquisition is much longer and averaged over the whole respiratory cycle. The activity of the lesion is underestimated due to an attenuation correction artefact. This artefact stems from the fact that lung tissue is less attenuating than liver tissue and so the reconstruction process under-corrects for the attenuation of the signal from the lesion when it is assumed to be in the lung. The lesion demonstrates intense uptake and so is still highly visible despite the attenuation correction artefact.

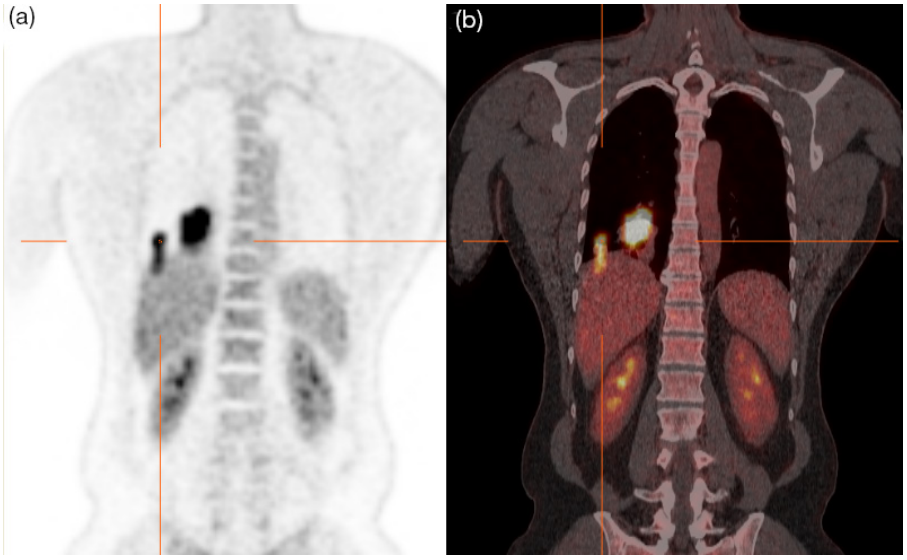


FIG. I.24. (a) Coronal PET image showing an area of focal uptake that appears to be both in the liver and in the lung, as well as another larger area that appears to be entirely in the lung. (b) Fused coronal PET/CT image showing a mis-registration in the larger lesion. Both of these lesions are entirely contained in the lung and the elongated appearance of the smaller lesions is an artefact created by respiratory motion.

of this for the physicist is the necessity to regularly perform a check of the standardized uptake value (SUV). The SUV is a quantitative parameter often quoted in clinical PET reporting that represents the uptake of activity in a lesion relative to background or healthy tissue (which should have an SUV = 1). The SUV measure is highly dependent on patient preparation, scanning protocol and reconstruction technique, and should be used with caution. It also relies heavily on accurate scanner calibration relative to the department dose calibrator, which allows PET data to be quantitative. Despite these difficulties, this index is often used by physicians for indicating abnormal uptake and, in particular, monitoring patient response during treatment by comparison of the SUV at baseline to the SUV during or after therapy. As such, the physicist must verify that such measures are accurate. A monthly check of the scanner SUV should be performed using a phantom of known volume, which, if activity is homogeneous and the scanner and dose calibrator are correctly calibrated, should produce an SUV = 1. Erroneously low SUVs may indicate that the physicist needs to recalibrate the dose calibrator and PET scanner, through the calculation of a new calibration factor.

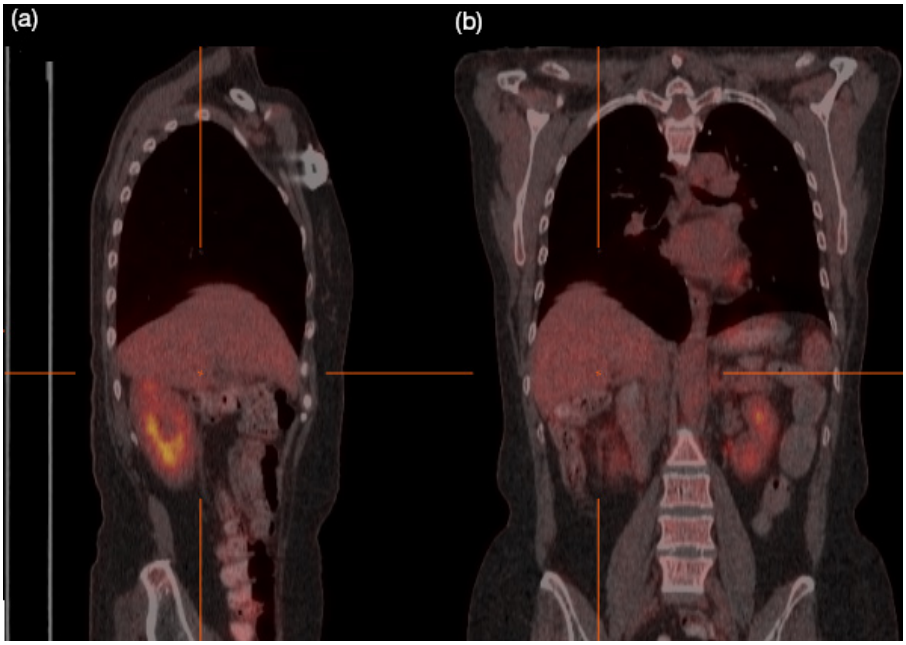


FIG. I.25. (a) A sagittal image shows a step-like artefact in the liver. (b) The same step-like artefact is seen on the coronal views. This problem is caused by the patient breathing during the CT acquisition and distorting the size of the liver. These artefacts are very common and can be compensated for by using a breath-hold technique.

This discussion of artefacts in PET/CT is by no means exhaustive and the reader is referred to the IAEA's PET/CT Atlas on Quality Control and Image Artefacts for a more comprehensive set of examples. As with all other instruments of the department, developing expertise in PET and PET/CT is essential for trouble-shooting and recognizing artefacts. Regular QC is a crucial factor in reducing artefacts due to the tomographic and/or CT system. Users of PET and PET/CT should be alert at all times to unexpected artefacts. A comparison between attenuation and scatter corrected images with non-corrected images should be part of routine clinical practice.

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