Combined Procedure Guidelines of SNM, EANM and BNMS for SPECT/CT and PETCT Imaging

(Adapted from SNM Procedure Guideline on SPECT/CT, with principle authors Dominique Delbeke[1], R. Edward Coleman[2], Milton J. Guiberteau[3], Manuel L. Brown[4], Henry D. Royal[5], Barry A. Siegel[5], David W. Townsend[6], Lincoln L. Berland[7], J. Anthony Parker[8], George Zubal[9] and Valerie Cronin[10]

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I. PURPOSE

The purpose of this Procedure Guideline is to assist physicians and radiologists in recommending, performing, interpreting, and reporting the results of SPECT/CT for imaging of adult and pediatric patients.

II. BACKGROUND INFORMATION AND DEFINITIONS

SPECT is a tomographic scintigraphic technique in which a computer-generated image of local radioactive tracer distribution in tissues is produced through the detection of single-photon emissions from radionuclides introduced into the body. CT is a tomographic imaging technique that uses an external x-ray source to produce 3-dimensional anatomic image data. The first SPECT/CT system combined a dual-head gamma camera and an integrated x-ray transmission system mounted on the same gantry. The CT image is used for attenuation correction as well as anatomic imaging, and the CT and SPECT images are fused, with computer assistance, for display. More recently, additional integrated SPECT/CT devices have become available, including systems combining a state-of-the-art multi-head gamma camera and multi-detector CT scanner side by side with a common imaging table. Combined SPECT/CT devices provide both the functional information from SPECT and the anatomic information from CT in a single examination. Some studies have demonstrated that the information obtained by SPECT/CT is more accurate in evaluating patients than that obtained from either SPECT or CT alone.

SPECT and CT are proven diagnostic procedures. Although techniques for registration and fusion of images obtained from separate SPECT and CT scanners have been available for several

years, the advantages of having SPECT and CT integrated into a single device have resulted in the development of this technology throughout the world. This Procedure Guideline pertains only to combined SPECT/CT devices.

Definitions

A. A SPECT/CT scanner is an integrated device containing both a CT scanner and a SPECT gamma camera with a single patient table and therefore capable of obtaining a CT scan, a SPECT scan, or both. If the patient does not move on the bed between the scans, the reconstructed SPECT and CT images will be spatially registered.
B. SPECT/CT registration is the process of aligning SPECT and CT images for the purposes of combined image display (fusion) and image analysis.
C. SPECT/CT fusion is the combined display of registered SPECT and CT image sets. Superimposed data typically are displayed with the SPECT data color coded to the CT data in gray scale.
D. SPECT/CT acquisitions can include the whole body, a limited portion of the body, or an organ.
E. The method of attenuation correction is the use of CT transmission data with SPECT/CT scanners.

III. EXAMPLES OF CLINICAL OR RESEARCH APPLICATIONS

Indications for SPECT/CT include but are not limited to imaging of the following:

A. Tumours
B. Thyroid disorders
C. Parathyroid disorders
D. Skeleton disorders
E. Inflammation or infection
F. Lymphatic system
G. Heart disorders
H. Brain disorders
I. Other organs

IV. PROCEDURE

A. Patient Preparation

1. Pregnancy and breast-feeding: See the Society of Nuclear Medicine Procedure Guideline for General Imaging.
2. Before arrival: See the specific Society of Nuclear Medicine Procedure Guideline for the SPECT radiopharmaceutical used.
3. Before injection
    a. See the specific Society of Nuclear Medicine Procedure Guideline for the SPECT radiopharmaceutical used.

b. For either a CT scan done for attenuation correction/anatomic localization (AC/AL) or a diagnostic CT scan of the abdomen or pelvis, an intravenous or intraluminal gastrointestinal contrast agent may be administered to provide adequate visualization of the gastrointestinal tract unless medically contraindicated or unnecessary for the clinical indication (see Section E.2.b).

B. Information Pertinent to Performing Procedure
See also the Procedure Guidelines for General Imaging and the specific Guidelines for the SPECT radiopharmaceutical used.

1. A focused relevant history related to the type of SPECT study performed
2. Patient's ability to lie still for the duration of the acquisition (15–45 min)
3. History of claustrophobia
4. Patient's ability to put his or her arms overhead, if applicable

C. Precautions
See the Guidelines for General Imaging.

D. Radiopharmaceutical
See the specific Guidelines for the radiopharmaceutical used.

With SPECT/CT, the radiation dose to the patient is the combination of the radiation dose from the SPECT radiopharmaceutical and the radiation dose from the CT portion of the study. Radiation dose in diagnostic CT has attracted considerable attention in recent years, in particular for paediatric examinations. It can be very misleading to state a "representative" dose for a CT scan because of the wide diversity of applications, protocols, and CT systems. This caveat also applies to the CT component of a SPECT/CT study. For example, a body scan may include various portions of the body and may use protocols aimed to reduce the radiation dose to the patient or aimed to optimize the CT scan for diagnostic purposes. The effective dose varies widely according to acquisition factors and can range from approximately 2 to 80 mSv (0.2–8.0 rems) for these options. It is therefore advisable to estimate the CT dose specific to the CT system and protocol being used.

Paediatric and adolescent patients should have their CT examinations performed at milliampere-seconds settings appropriate for patient size, regardless of the CT protocol used, because radiation dose to the patient increases significantly as the diameter of the patient decreases.

Radiopharmaceutical doses should also be adjusted for the size of the patient and the information required.

E. Image Acquisition: See also the specific Procedure Guidelines for various SPECT procedures, the Procedure Guideline for General Imaging, and the "Specifications of the Examination" and "Documentation" sections of Practice Guideline for the Performance of Computed Tomography of the Extracranial Head and Neck in Adults and Children, the Practice Guideline for the

Performance of Paediatric and Adult Thoracic Computed Tomography (CT), and the Practice Guideline for the Performance of Computed Tomography (CT) of the Abdomen and Computed Tomography (CT) of the Pelvis.

1. Field of view, positioning, and preacquisition preparation
    a. See the specific Procedure Guideline for the pathophysiology being imaged.
    b. Arms along the sides may produce artifacts over the torso. For optimal imaging of the body, the arms should be elevated over the head if tolerated by the patient. For optimal imaging of the head and neck, the arms should be positioned along the sides.
    c. For radiopharmaceuticals excreted primarily by the kidneys, the patient should void the bladder before acquisition of the images.
    d. Metallic objects should be removed from the patient whenever possible.

2. Protocol for CT imaging
    The CT component of a SPECT/CT examination can be performed either for attenuation correction and AC/AL or as an optimized diagnostic CT scan. An AC/AL CT scan has not necessarily been optimized as a diagnostic CT examination, whereas for diagnostic CT, such optimization has been attempted. In some circumstances, both an initial CT acquisition for AC/AL (before the SPECT data acquisition) and diagnostic CT (after the SPECT data acquisition) are performed. Optimization of the CT technique used in SPECT/CT continues to evolve.
    a. If the CT scan is obtained for AC/AL, use of a low milliampere-seconds setting is recommended to decrease the radiation dose to the patient.
    b. For an optimized diagnostic CT scan, standard CT milliampere-seconds settings are recommended to optimize the spatial resolution of the CT scan. Tube current modulation may be used to minimize radiation dose to the patient. In some cases, intravenous or oral contrast material may be used. A separate CT acquisition may be necessary to produce an optimized diagnostic CT scan that is requested for a particular region of the body. For many indications, the examination is performed with intravenous contrast material and appropriate injection techniques. High concentrations of intravenous contrast agents may cause an attenuation-correction artifact on the SPECT image, but the impact usually is modest. This artifact may be minimized on scanners by use of appropriate correction factors. The energy of the emission, typically lower for SPECT than for PET, may require different techniques according to the radionuclide used.
    c. For either a CT scan done for AC/AL or an optimized diagnostic CT scan of the abdomen or pelvis, an intraluminal gastrointestinal contrast agent may be administered to provide adequate visualization of the gastrointestinal tract unless medically contraindicated or unnecessary for the clinical indication. This agent may be a positive contrast agent (such as dilute barium or an oral iodinated contrast agent) or a negative contrast agent (such as water). Collections of highly

concentrated barium or iodinated contrast agents may result in attenuation-correction artifacts. Other dilute positive and negative oral agents are less likely to affect SPECT image quality.

d. With regard to the breathing protocol for CT transmission scanning, in SPECT/CT, the position of the diaphragm on the SPECT emission scan should match as closely as possible that on the CT transmission images. Although a diagnostic CT scan of the chest typically is acquired during end-inspiration breath holding, this technique is not optimal for SPECT/CT because it may result in substantial respiratory motion misregistration on SPECT and CT images. Some facilities perform CT transmission scans during breath holding at mid-inspiration volume, and others prefer that the patient continue shallow breathing during the CT acquisition. The differences in respiratory cycles between CT and SPECT may result in inaccurate attenuation correction for SPECT data at the lung–liver interface. Respiratory motion results in inaccurate localization of lesions at the base and periphery of the lungs, at the dome of the liver, or near any lung–soft-tissue interface.

3. Protocol for SPECT emission imaging: See the specific Procedure Guideline for the organ being imaged.

F. Interventions

See the specific Procedure Guideline for the organ being imaged.

G. Processing

1. SPECT reconstruction: See the specific Procedure Guideline for the organ being imaged.
2. CT reconstruction: CT sinograms that are used for attenuation correction of SPECT emission data are reconstructed by filtered backprojection at the full field of view, whereas those that are used for CT interpretation are reconstructed separately, with appropriate zoom, slice thickness, slice overlap, and reconstruction algorithms for the particular region of the body scanned. The filtered backprojection can be either 2-dimensional after appropriate portions of the spiral CT data are collected into axial or tilted planes or fully 3-dimensional. In addition to the reconstruction kernel that adjusts in-plane features, such as spatial resolution and noise texture, longitudinal filtration (along the *z*-axis) is used to modify the *z*-resolution and the slice-sensitivity profiles. In addition, there are techniques to emphasize certain image features, for example, bone, lung, or brain algorithms. For attenuation correction, only the standard kernels are used. Because CT volumes today are nearly isotropic, reformatting such as coronal, sagittal, or even curved displays is often preferred. Advanced display techniques, such as volume rendering and maximum- or minimum-intensity projections applied to the complete volume or to thick, arbitrarily oriented sections, are often used. Organ- and task-specific automatic or semiautomatic segmentation algorithms and special evaluation algorithms also are in routine use.

3. Display: With an integrated SPECT/CT system, typically the software packages provide registered and aligned CT images, SPECT images, and fusion images in the axial, coronal, and sagittal planes as well as maximum-intensity-projection images for review in the 3-dimensional cine mode. SPECT images with and without attenuation correction should be available for review.

H. Interpretation Criteria

See the specific Procedure Guideline for the organ being imaged.

I. Reporting

See also the Procedure Guideline for General Imaging.

1. Study identification
2. Clinical information
    a. Report the indication for the study.
    b. Report any relevant history.
3. Procedure description and imaging protocol
    a. Radiopharmaceutical: Describe the choice of radiopharmaceutical, the administered activity, the route of administration, and the uptake time.
    b. Other drugs administered and procedures performed: These include placement of an intravenous line; hydration; insertion of a Foley catheter (size of catheter); administration of frusemide (dose, route, and time), muscle relaxants, or pain medications; and sedation procedures (choice of procedure, type of medication and time of sedation in relation to radiotracer injection, and patient's condition at the conclusion of the SPECT study).
    c. Field of view and patient positioning: Specify whether imaging was of the whole body, from the skull base to mid thigh, or of a limited area, and describe the position of the arms.
    d. CT transmission protocol: For AC/AL or diagnostic CT, describe whether the protocol included oral or intravenous contrast material and in what way the protocol was appropriate for the clinical scenario and body region of interest.
    e. SPECT emission protocol: See the Guideline for General Imaging.
4. Description of findings
    a. Quality of the study: Describe, for example, whether the study was limited because of motion or because of an unusual distribution of the radiopharmaceutical.
    b. Location, extent, and intensity of abnormal radiopharmaceutical uptake: Describe these findings in relation to uptake in normal comparable tissues and describe the relevant morphologic findings related to SPECT abnormalities on the CT images. An estimate of the intensity of uptake may be described as mild, moderate, or intense or in relation to a reference standard. The integrated SPECT/CT report should include any detected incidental findings on the CT scan that are relevant to patient care. If the CT scan was requested and performed as a diagnostic examination, then the CT component of the study may be reported separately, if necessary, to satisfy regulatory, administrative, or reimbursement requirements. In that case, the SPECT/CT report can refer to the diagnostic CT scan report for findings not related to the SPECT/CT combined findings.

c. Limitations: When appropriate, identify factors that can limit the sensitivity and specificity of the examination (e.g., small lesions).
d. Clinical issues: Address or answer any pertinent clinical questions raised in the request for the imaging examination.
e. Comparative data: Comparisons with previous examinations and reports, whenever possible, should be part of the radiologic / nuclear medicine report.

5. Impression (conclusion or diagnosis)
    a. Whenever possible, a precise diagnosis should be given.
    b. When appropriate, a differential diagnosis should be given.
    c. When appropriate, follow-up and additional diagnostic studies needed to clarify or confirm the impression should be recommended.

J. Quality Control

1. Radiopharmaceuticals: See the relevant Procedure Guidelines for Use of Radiopharmaceuticals.
2. Instrumentation specifications: See also the relevant Procedure Guideline for SPECT Imaging (to be developed) and the "Equipment Specifications" and "Quality Control" sections from the relevant Practice Guidelines for the Performance of Computed Tomography of the Extracranial Head and Neck in Adults and Children, the Practice Guidelines for the Performance of Pediatric and Adult Thoracic Computed Tomography (CT), and the Practice Guidelines for the Performance of Computed Tomography (CT) of the Abdomen and Computed Tomography (CT) of the Pelvis.
    a. Equipment performance guidelines
    A spectrum of integrated SPECT/CT systems is available commercially, and this technology is still evolving. The performance of these systems depends on the SPECT and CT components that are integrated.
    The quality and resolution of the CT images depend on the performance of the CT system. The diagnostic information on the CT images may be limited by the capabilities of the system. On the low-end systems, the CT component has been designed primarily to provide attenuation maps with a minimal radiation dose to the patient, resulting in poor quality and poor resolution of the CT images. On the high-end systems, high-performance multidetector CT systems have been integrated with SPECT systems in order to perform high-resolution CT in combination with various SPECT radiopharmaceuticals and coronary CT angiography in combination with SPECT myocardial perfusion.
    There is a spectrum of SPECT gamma cameras in these combined SPECT/CT systems as well, some optimized for body imaging and some for cardiac imaging. A workstation with the capability to display CT, SPECT, and fused images with different percentages of CT and SPECT blending should be available. The workstation should allow multiplanar display with linked CT and SPECT cursors.

Post-collection registration of the SPECT and CT datasets and registration with other imaging studies, including non-rigid registration, are desirable.

b. Equipment quality control
SPECT performance monitoring should be in accordance with the relevant Procedure Guidelines for General Imaging.
CT monitoring should be in accordance with the appropriate Technical Standard for Medical Physics Performance Monitoring of Computed Tomography (CT) Equipment.
The quality control procedures for SPECT/CT should incorporate both CT procedures and SPECT procedures according to the Society of Nuclear Medicine Procedure Guideline for General Imaging and ACR Technical Standards. The quality control procedures for CT should include air and water calibrations in Hounsfield units for a range of kilovolts. The quality control procedures for SPECT should include a calibration measurement of activity in a phantom containing a known concentration, generally as a function of axial position within the scanner field of view. A daily check on the stability of the individual detectors should also be performed to identify detector failures and drifts.
In addition, for SPECT/CT, a check on the alignment between the CT and SPECT scanners should be performed periodically. Such a gantry alignment check should determine any offset between the CT and SPECT scanners to be incorporated into the fused image display to ensure accurate image alignment.

3. Emergency procedures: An emergency cart containing appropriate medications and resuscitation equipment must be readily available to treat adverse contrast material reactions.

K. Sources of Error

See also the relevant Procedure Guidelines for the organ being imaged. Some of the technical sources of error seen with standard SPECT procedures are also present with SPECT/CT.

1. SPECT/CT image fusion errors
    a. Movement in the interval between SPECT and CT data collection
        - Whole-body or extremity motion
        - Diaphragmatic motion with breathing
        - Bowel motility
        - Contrast motion or change in contrast concentration
        - Rapid filling of urinary bladder

    b. Attenuation artifacts
        - Particularly dense materials such as dental work
        - Metallic implants
        - Lack of data for CT technique

c. Software misalignment of SPECT and CT data

2. Display errors
    a. Inadequate windowing of SPECT or CT data on fused images
    b. Inadequate windowing of SPECT or CT data when viewed separately
    c. Cursor misalignment on SPECT and CT images
    d. Inappropriate color table selection for SPECT data

V. QUALIFICATION OF PERSONNEL

See also the relevant Procedure Guideline for Tumor Imaging Using ^{18}F-FDG PET/CT.

A. Physicians and Radiologists

The issue of training nuclear medicine physicians and radionuclide radiologists to interpret the CT and SPECT components of SPECT/CT is similar to that for the PET and CT components of PET/CT. (There are ongoing discussions in the United Kingdom between the officers of the Royal College of Radiologists and the Nuclear Medicine Specialist Training Committee).

(In the USA an article summarizing discussions regarding issues relating to imaging with PET, CT, and PET/CT was published by a collaborative working group with representatives from the ACR, the Society of Nuclear Medicine (SNM), and the Society of Computed Body Tomography and Magnetic Resonance (*J Nucl Med.* 2005;46:1225–1239). These organizations agree that only appropriately trained, qualified physicians should interpret PET/CT images). Traditionally, in the USA, appropriate training has been quantified by the number of continuing medical education credits earned and the number of cases interpreted. The collaborative working group recommends that practicing nuclear physicians receive on-the-job CT training that includes earning 100 h of CT continuing medical education credit and interpreting 500 CT cases under the supervision of a diagnostic radiologist who is qualified as defined in the ACR Practice Guidelines for Performing and Interpreting Diagnostic Computed Tomography. The CT cases should include a reasonable distribution of those involving the head and neck, chest, abdomen, and pelvis. Alternative approaches, such as determining the accuracy of each physician's/radiologist's interpretation compared with that of his or her peers by use of a workstation simulator and a report generation and scoring system, may have equal or greater validity.

In the future, it is recommended that the requirements of radionuclide radiology and nuclear medicine training programs will include training in the interpretation and supervision of integrated SPECT/CT and PET/CT studies. Revalidation will include testing competencies in CT, SPECT, and SPECT/CT (as well as CT, PET and PET/CT). Eligibility for being revalidated will mandate participation in the maintenance-of-appropriate specific CPD program and will include

training in the interpretation of SPECT, CT, and SPECT/CT. Some components of the maintenance-of-certification program will include evaluation of the accuracy of each radiologist's / physician's interpretation of images compared with that of his or her peers by use of a workstation simulator and a report generation and scoring system. Performing and interpreting radiologists/physicians should participate in and be able to show evidence of participation in continuing medical education on the techniques and interpretation related to the procedures discussed in this Procedure Guideline. Where maintenance-of-certification programs exist, radiologists/physicians should be able to show evidence of participation.

B. Technologists

SPECT/CT and PET/CT technology present similar practice issues regarding the education, training, and certification of technologists to become appropriately qualified and competent to perform the CT portion of the study. Additional issues arise with regard to ensuring competency, standardizing the educational experience of these individuals, and barriers placed by licensure and regulation at the state level. In the USA, the Society of Nuclear Medicine Technologist Section (SNMTS) and the American Society of Radiologic Technologists (ASRT) have come together to develop a master plan and set into motion mechanisms to sort out the practice issues surrounding PET/CT. This master plan was crafted during a stakeholders' meeting—known as the PET/CT Consensus Conference—that was held in July 2002. The recommendations from this meeting can be found in a report of the PET/CT Consensus Conference (*J Nucl Med Technol.* 2002:30;201–204) and are also accessible on the SNM Web site (www.snm.org).

It is the responsibility of the professional associations in the UK and Europe to establish standards, delineate mechanisms for obtaining the training necessary to promote a qualified and competent workforce to perform these procedures, and collaborate with organizations that can assist in sorting out practice issues. To address educational needs, the ASRT and SNMTS spearheaded the development of a PET/CT curriculum, which was endorsed by numerous professional organizations and distributed to the radiation control board of each state and to every program director in the United States; it is also posted on the SNM Web site (www.snm.org) and the ASRT Web site (www.asrt.org).

The American Registry of Radiologic Technologists (ARRT) has adapted its CT certification examination and has allowed certified or registered nuclear medicine technologists who have met the required prerequisites to take this examination. Eligibility criteria are located on the ARRT Web site (www.arrt.org).

Licensure and regulation definitely are affecting the opportunities that nuclear medicine technologists have for obtaining the CT experience needed to take the ARRT CT examination. The SNMTS is approaching these issues through both legislative and regulatory pathways. The SNMTS has been promoting the Consumer Assurance of Radiologic Excellence bills pending before the U.S. Congress. These bills would establish minimum education and credentialing standards for those who perform medical imaging and therapeutic procedures. The second pathway recognizes the regulatory route in addressing these practice issues through a collaborative liaison relationship that has been established with the Conference of Radiation Control Program Directors (www.crcpd.org), the professional organization of state radiation regulators.

C. Qualified Medical Physicists

A qualified medical physicist is an individual who is competent to practice independently one or more of the subfields of medical physics. The SNM considers certification and continuing education in the appropriate subfield(s) to demonstrate that an individual is competent to practice one or more of the subfield(s) of medical physics and to be a qualified medical physicist. The SNM recommends that the individual be certified in the appropriate subfield(s) by the American Board of Radiology (ABR) or the American Board of Science in Nuclear Medicine (ABSNM).

The appropriate subfields of medical physics are as follows: medical nuclear physics, with initially at least 15 h of continuing education credit in CT physics (ABR); diagnostic radiologic physics, with initially at least 15 h of continuing education credit in SPECT physics (ABR); and nuclear medicine physics and instrumentation, with initially at least 15 h of continuing education credit in CT physics (ABSNM).

A qualified medical physicist must have at least 40 h of practical experience providing physics support for both the SPECT and the CT components in an established SPECT/CT facility.

A qualified medical physicist's continuing education should be in accordance with the ACR Practice Guideline for Continuing Education and should include at least 15 h in SPECT and CT physics combined in a 3-y period.

A qualified medical physicist or other qualified scientist performing physics services in support of a SPECT/CT facility should meet all of the following criteria:

1. Advanced training directed at the specific area of responsibility (e.g., medical physics, health physics, or instrumentation)
2. Licensure, if required by state regulations
3. Documented regular participation in continuing education in the area of specific involvement to maintain competency
4. Knowledge of radiation safety and protection and of all rules and regulations applying to the area of practice

VI. ISSUES REQUIRING FURTHER CLARIFICATION

Use of AC/AL CT, optimized diagnostic CT, or both may depend on the indication.

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VIII. DISCLAIMER

The SNM wrote and approved the original of this Procedure Guideline as an educational tool designed to promote the cost-effective use of high-quality nuclear medicine procedures in medical practice or in the conduct of research and to assist practitioners in providing appropriate care for patients. T has been modified for use by the British Nuclear Medicine Society (BNMS) with changes being made to be more appropriate for UK practitioners. The Procedure Guideline should not be deemed inclusive of all proper procedures or exclusive of other procedures

reasonably directed to obtaining the same results. The guidelines are neither inflexible rules nor requirements of practice and are not intended nor should they be used to establish a legal standard of care. For these reasons, the SNM cautions against the use of this Procedure Guideline in litigation in which the clinical decisions of a practitioner are called into question.

The ultimate judgment about the propriety of any specific procedure or course of action must be made by the practitioner when considering the circumstances presented. Therefore, an approach that differs from the Procedure Guideline is not necessarily below the standard of care. A conscientious practitioner may responsibly adopt a course of action different from that set forth in the Procedure Guideline when, in his or her reasonable judgment, that course of action is indicated by the condition of the patient, limitations on available resources, or advances in knowledge or technology subsequent to publication of the Procedure Guideline.

All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The sole purpose of this Procedure Guideline is to assist practitioners in achieving this objective.

Advances in medicine occur at a rapid rate. The date of a Procedure Guideline should always be considered in determining its current applicability.

IX. APPROVAL

The original of this Procedure Guideline was approved by the Board of Directors of the SNM on April 30, 2006.

FOOTNOTES

* YOU CAN ACCESS THIS ACTIVITY THROUGH THE SNM WEB SITE (http://www.snm.org/guidelines).

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FDG PET and PET/CT: BNMS Guideline adapted from EANM procedure guideline for tumour PET imaging: version 1.0

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Abstract: The aim of this guideline is to provide a minimum standard for the acquisition and interpretation of PET and PET/CT scans with [18F]-fluorodeoxyglucose (FDG). This guideline will therefore address general information about [18F]-fluorodeoxyglucose (FDG) positron emission tomography-computed tomography (PET/CT) and is provided to help the physician and physicist to assist to carrying out, interpret, and document quantitative FDG PET/CT examinations, but will concentrate on the optimisation of diagnostic quality and quantitative information.

Keywords: Guideline FDG PET PET/CT. Tumour Oncology Quantification QC QA

Introduction

The aim of this guideline is to provide a minimum standard for the acquisition and interpretation of PET. Minor modification has been made for use in the UK as a BNMS Guideline.

The original of this guideline was a joint project of the EANM Oncology Committee and the EANM Physics Committee. In addition, this guideline is based on the following three documents:

(1) DGN (Deutsche Gesellschaft für Nuklearmedizin) Leitlinie: "FDG-PET/CT in der Onkologie" by Krause BJ, Beyer T, Bockisch A, Delbeke D, Kotzerke J, Minkov V, Reiser M, Willich N, Arbeitsausschuss Positronenemissionstomographie der Deutschen Gesellschaft für Nuklearmedizin. 2007.

(2) SNM Guidelines: "Procedure Guidelines for tumour imaging with 18F-FDG PET/CT 1.0." by Delbeke D, Coleman RE, Guiberteau MF, Brown ML, Royal HD, Siegel BA, Townsend DW, Berland LL, Parker JA, Hubner K, Stabin MG, Zubal G, Kachelries M, Cronin V, Holbrook S. 2006.

(3) "Applications of F18-FDG-PET in Oncology and Standardisation for Multi-Centre Studies" by Boellaard R, Oyen WJG, Hoekstra CJ, Hoekstra OS, Visser EP, Willemsen AT, Arends AJ, Verzijlbergen JF, Paans AM, Comans EFI, Lugtenburg E, Stoker J, Schaefer-Prokop C, Zijlstra JM, Pruim J. HOVON Imaging workgroup and the Netherlands Society of Nuclear Medicine. 2007 R. Boellaard (*) : O. S. Hoekstra : E. F. I. Comans : A. A. Lammertsma Department of

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Eur J Nucl Med Mol Imaging DOI 10.1007/s00259-009-1297-4 and PET/CT scans with [18F]-fluorodeoxyglucose (FDG).

PET is a quantitative imaging technique and therefore requires a common quality control (QC)/quality assurance (QA) procedure to ensure that optimal images are acquired for our patients and that these images would be acceptable and interpretable by any clinician in another hospital. This is essential for the management of patients who have the right to have their health care provided in any hospital they chose. Common standards will help promote the use of PET/CT imaging and increase the value of publications and their contribution to evidence-based medicine and potentially enable the role of semi-quantitative and quantitative image interpretation since the numeric values should be consistent between platforms and institutes that acquire the data. FDG PET/CT is being used increasingly to evaluate tumour response in addition to diagnosis and staging of tumours. Increasingly, research is being performed in radiotherapy planning and it will be important that areas such as edge detection of tumours have a translatable measurement. This guideline will therefore address general information about [18F]-fluorodeoxyglucose (FDG) positron emission tomography-computed tomography (PET/CT) and is provided to help the trained physician/radiologist and physicist to assist in carrying out, interpreting and documenting quantitative FDG PET/CT examinations, but will concentrate on the optimisation of diagnostic quality and quantitative information.

Note that in this guideline quantification of FDG PET and PET/CT is defined as quantification using standardised uptake values (SUV), as it represents the most commonly used semi-quantitative parameter for analysis of oncology FDG PET studies. However, other fully quantitative measures, which require more complex data-collection procedures, are being used as well, but they are beyond the scope of the present guideline. In this guideline, areas of information will provide a minimum standard for FDG PET and PET/CT data acquisition, quality control, and quality assurance.

The Procedure Guidelines for Tumour Imaging with FDG PET/CT 1.0 of the Society of Nuclear Medicine

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Eur J Nucl Med Mol Imaging (SNM)1 [1], the German Guidelines for FDG-PET/CT in Oncology2 [2], the quality control/assurance procedures used in the UK for lymphoma/head and neck cancer studies and the Netherlands protocol for standardisation of quantitative whole-body FDG PET/CT [3] studies have been integrated in the present guideline. An overview of other and previously published guidelines [1, 2, 4–14] or recommendations can be found in the supplement issue of the Journal of Nuclear Medicine 2009 [15].

Principle Positron emission tomography (PET) is a tomographic technique that computes the three-dimensional distribution of radioactivity based on the annihilation photons that are emitted by positron emitter labelled radiotracers. PET allows non-invasive quantitative assessment of biochemical and functional processes. The most commonly used tracer at present is the glucose analogue FDG. FDG accumulation in tissue is proportional to the amount of glucose utilization. Increased consumption of glucose is a characteristic of most cancers and is in part related to over-expression of the GLUT-1 glucose transporters and increased hexokinase activity. Given the kinetics of FDG adequate static images are most frequently acquired approximately 60 min after administration. It is recognized, however, that the uptake period is highly variable, FDG concentration not reaching a plateau for up to 4–6 h in some tumours [16]. Moreover, not all cancers are FDG avid. Variable uptake is likely related to biological features of individual cancers, as is observed in bronchoalveolar carcinomas, renal, thyroid cancers, several subtypes of malignant lymphoma, carcinoids but also most prostate carcinomas. The reason and prognostic relevance of this biological heterogeneity is not always clear. However, in the majority of cases, FDG PET is a sensitive imaging modality for the detection, staging, re-staging as well as for assessment of therapy response in oncology [6, 17–25].
In contrast to PET, computed tomography (CT) uses an x-ray beam to generate tomographic images. CT allows the visualisation of morphological and anatomic structures with a high anatomical resolution. Anatomical and morphological information derived from CT can be used to increase the precision of localization, extent, and characterisation of lesions detected by FDG PET. FDG PET and CT are established imaging modalities that have been extensively validated in routine clinical practice. Integrated PET/CT combines PET and CT in a single imaging device and allows morphological and functional imaging to be carried out in a single imaging procedure. Integrated PET/CT has been shown to be more accurate for lesion localisation and characterisation than PET and CT alone or the results obtained from PET and CT separately and interpreted side by side or following software based fusion of the PET and CT datasets. PET/CT gains more and more importance in oncology imaging. At the same time, there is greater awareness that the quantitative features of PET may have a major impact in oncology trials and clinical practice. Therefore this guideline focuses on the use of FDG PET/CT in oncology.
Definitions & An integrated PET/CT system is a combination of PET and a CT scanner with a single patient table & PET/CT allows a sequential acquisition of corresponding PET and CT

portions of the examination without having to move the patient. Both data sets are intrinsically coregistered given that the patient does not move during or in between the acquisitions.
The PET+ CT fusion is the mechanical and data related fusion of PET and CT volume data sets in a combined data set. The software fusion of separate PET and CT data sets is referred to as PET+CT.& A fused PET+CT data set allows the combined visualisation of the fused PET and CT datasets for different portions of the body, as follows.

Total body imaging: from the top of the head through the feet (only in a minority of the cases).
Whole-body imaging: Base of the skull-base to mid-thigh imaging (covers most of the relevant portions of the body in oncology imaging).

Limited area tumour imaging: (this being for the evaluation of tumour-related changes in a limited portion of the body).

In PET/CT attenuation and scatter correction is carried out using the CT-transmission data.

Low-dose (CT-AC) or used for anatomical co-localisation of PET findings (with reduced voltage and current of the x-ray

1 Sections of this document were adapted and reprinted with permission of the Society of Nuclear Medicine, Procedure Guidelines for Tumour Imaging with 18F-FDG PET/CT: Delbeke D (chair), Coleman RE, Guiberteau MJ, Brown ML, Royal HD, Siegel BA, Townsend DW, Berland LL, Parker JA, Hubner K, Stabin MJ, Zubal G, Kachelreiss M, Cronin V, Hoolbrook S. J Nucl Med 2006; 47: 885–895
2 Sections of this document were translated and reprinted with permission of the DGN (Deutsche Gesellschaft für Nuklearmedizin): Krause BJ, Beyer T, Bockisch A, Delbeke D, Kotzerke J, Minkov V, Reiser M, Willich N und der Arbeitsausschuss Positronen-Emissions-Tomographie der Deutschen Gessellschaft für Nuklearmedizin. FDG-PET/CT in oncology German Guideline. Nuklearmedizin 2007; 46: 291–301 Eur J Nucl Med Mol Imaging beam), i.e. a low-dose CT is NOT intended for radiological diagnosis. & If clinically indicated, a proper ‘diagnostic’ CT scan with intravenous and/or oral contrast media and deep inspiration breath hold can typically be combined with the PET/low-dose CT acquisition.

Indications
PET is a rapidly ‘evolving’ field at both the national and international level, with sometimes striking differences between individual countries. The summary below is therefore subjective in nature and based on a combination of expert experience and scientific literature [6, 17, 18, 20–26]. an excellent overview is given in [6], but these indications are constantly changing and require updating with time.

Primary presentation: diagnosis: unknown primary malignancy, differentiation of benign and malignant lesions of e.g. a solitary lung nodule, especially in case of discrepant clinical and radiological estimates of the likelihood of cancer);

Staging on presentation: non-small-cell lung cancer, T3 oesophageal cancer, Hodgkin's disease, non-Hodgkin's lymphoma, locally advanced cervical cancer, ENT tumours with risk factors and locally advanced breast cancer.

Response evaluation: malignant lymphoma, GIST, at present other applications only in a research setting. Application for oesophageal, colorectal, lung and breast cancer appear promising.

Restaging in the event of potentially curable relapse (for FDG avid tumours)

Establishing and localising disease sites as a cause for elevated serum markers (e.g. colorectal, thyroid, ovarian, cervix, melanoma, breast and germ–cell tumours)

Image guided biopsy (e.g. brain tumours) and radiotherapy planning
Data that should accompany the request for a PET/CT study

Indication, reason for request of PET or PET/CT study (see Indications)

Height and body weight (these must be determined precisely in the case of SUV measurements, (see below).
With serial studies in the same patient, weight must be measured directly prior to each PET study because body weight often changes during course of disease.
(If known) tumour type, tumour sites that have already been noted
Oncology prior history, relevant co-morbidity (especially inflammation)
Diabetes mellitus (including medication)
Results of other imaging tests (especially CT, MRI)
In case of therapy evaluation: type and date of last therapeutic intervention
Allergy for contrast agents
Renal function
Radiopharmaceutical
Product: [18F]-fluorodeoxyglucose (FDG)
Nuclide: Fluorine-18
Dosage: Dependent on the system and the patient's weight. (See Performing the PET/CT study).
Administration: Intravenous
Synthesis and
Quality Control: Conform the European Pharmacopeia
Patient preparation:
The main purpose of the patient preparation is the reduction of tracer uptake in normal tissue (kidneys, bladder, skeletal muscle, myocardium, brown fat) while maintaining and optimising tracer uptake in the target structures (tumour tissue). In the following, a generally applicable protocol is outlined:
Patients are not allowed to consume any food or sugar for at least 6 h prior to the start of the PET study (i.e. with respect to time of injection of FDG). In practice, this means that patients scheduled to undergo the PET study in the morning should not eat after midnight and preferably have a light meal (no alcohol) during the evening prior to the PET study. Those scheduled for an

afternoon PET study may have a light breakfast before 8.00 a.m. (i.e. up to two sandwiches, no sugars or sugar containing sandwich filling). Medication can be taken as prescribed.
Adequate pre-hydration is important to ensure a sufficiently low FDG concentration of FDG in urine (less artefacts) and for radiation safety reasons (for example, 1 l of water in the 2 h prior to injection; where necessary, account for volume of water in oral contrast medium for a diagnostic CT scan). Eur J Nucl Med Mol Imaging
Parenteral nutrition and intravenous fluids containing glucose should be discontinued at least 4 h before the PET/CT examination. In addition, the infusion used to administer intravenous pre-hydration must not contain any glucose.
During the injection of FDG and the subsequent uptake phase the patient should remain seated or recumbent and silent to minimise FDG uptake in muscles. For a brain examination with FDG, injection should take place in a darkened and quiet room and the patient should stay there for the subsequent uptake phase to avoid areas of enhanced uptake due to brain activation.
The patient should be kept warm starting at 30–60 min before the injection of FDG and throughout the following uptake period and PET examination to minimise FDG accumulation in the brown fat (especially relevant if the room is air conditioned). Moreover, all patients must avoid (extreme) exercise for at least 6 h before the PET study (for example, they must not cycle to the hospital).

In case of pregnancy: see the Society of Nuclear Medicine Procedure Guidelines for General Imaging Version 3 or national guidelines.

The following recommendations apply to patients with diabetes mellitus:
type II diabetes mellitus (controlled by oral medication) – the PET study should preferably be performed in the late morning – patients must comply with the fasting rules indicated above - patients continue to take oral medication to control their blood sugar.
type I diabetes mellitus and insulin-dependent type II diabetes mellitus – ideally, an attempt should be made to achieve normal glycaemic values prior to the PET study, in consultation with the patient and his/her attending medical doctor – the PET study should be scheduled for late morning – the patient should eat a normal breakfast at 7.00 a.m. and inject the normal amount of insulin. Thereafter the patient should not consume any more food or fluids, apart from the prescribed amount of water. It is good practice to check the blood glucose level of the patient on arrival at the imaging centre to ensure the patients' sugar is not too low or high, since this may obviate an unnecessary wait. In the case of patients on continuous insulin infusion, the
PET study should if possible be scheduled early in the morning. The insulin pump is kept on the "night setting" until after the PET study. The patient can have breakfast after the PET study.

Extra notes
A transurethral catheter is placed only if required (expected urinary activity prohibiting appropriate image interpretation), and this should preferably be done before FDG is administered. Administration of a diuretic (frusemide) can be considered in the case of small pelvic tumours, but it is not necessary to use this routinely. Clinical experience suggests that proper prehydration avoids most potential reading errors and that delayed imaging or frusemide intervention is very rarely necessary
There is no reason for routine administration of sedatives (e.g. short-acting benzodiazepines). Sedatives can be considered in the case of tumours in the head and neck region to reduce muscle

uptake or in anxious claustrophobic patients. In the case of children, sedation may be required depending on the age or the tumour type. A number of agents have been tried and are being tested (e.g. beta-blockers) to reduce brown fat uptake. If an agent is to be used as part of a clinical trial it needs to be effective and must not affect tumour uptake of the radiopharmaceutical. Patients should be instructed not to drive a car after sedation.
Blood glucose level must be measured prior to administering FDG. A Glucometer or a similar bedside device (capable of performing overall euglycaemia measurements) can be used for this purpose, but a blood glucose test must be performed with a calibrated and validated method if plasma glucose level is used as correction of SUV measurements [27]: – If plasma glucose level is <7 mmol/l (or <120 mg/dl) the FDG PET study can be performed – If plasma glucose level is ≥7 mmol/l (or >120 mg/dl) the FDG PET study must be rescheduled or the patient excluded depending on the patient circumstances and the trial being conducted. – In case the study cannot be rescheduled or when elevated glucose levels cannot be ruled out, blood glucose levels must always be measured using a calibrated and validated method and SUV must be reported with and without glucose correction. Note that specifically in response-assessment studies blood glucose levels may change with the therapy and it is strongly recommended to measure blood glucose levels using validated and calibrated methods (no bedside devices) during all sequential PET examinations. – Reduction of the blood glucose level by administration of insulin can be considered, but the PET/CT examination should also be postponed depending on the type and route of the administration of insulin. N.B.: insulin must not be given to reduce glucose unless the interval between administration of insulin and administration of FDG is more than 4 h.
When diagnostic contrast-enhanced CT with intravenous contrast media is to be performed (after the PET/CT examination), indications, contraindications and restrictions have to be assessed by a qualified physician/radiologist. Medication that interacts with intravenous contrast (e.g. metformin for the treatment of diabetes) and relevant medical history (e.g. compromised renal function) have to be taken into consideration.
For CT of the abdomen or pelvis, an intraluminal gastrointestinal contrast agent may be administered to improve the visualisation of the gastrointestinal tract in CT (unless it is not necessary for the clinical indication or it is medically contraindicated). Contrast agents must only be used in accordance with the recommendations given in paragraph.
Other acquisition parameters, CT protocol. Essential data/aspects and required materials for the FDG PET study
Required materials
(Ideally) a triple-channel system (=standard system with three-way tap to enable saline flush) for administering the tracer and flushing with physiological saline. However, if automated bedside administration systems are being used then other types of lines may be required to obtain the same flushing and administration results.
Bedside glucose meter: to check serum glucose, especially in patients susceptible to hyperglycaemia (diabetics, patients taking corticosteroids). Note that many (other) bedside methods do not have sufficient precision to be used for SUV correction [27].
Weighing scales should be accredited and checked at least annually.
Clinical information required for scan procedure and interpretation
Before the PET/CT examination the following clinical data should be available: a history focused on the patients disease and localisation of disease, date of diagnosis, type of verification of diagnosis (biopsy results, time of biopsy, histopathological report) and prior therapies (surgery,

radiation therapy, chemotherapy, administration of bone marrow stimulants and steroids), current medication and previous imaging results
Relevant comorbidity: diabetes, concurrent inflammatory disease.
Prior therapy: nature and timing of last relevant surgery, radiation, chemotherapy, bone marrow stimulants and steroids. In clinical trials, the study protocol should define the interval between administration of such substances and the PET study. For clinical practice several recommendations have been published [7] (see also e.g. JNM Supplement 2009). A minimum interval between the last dose (chemotherapy) and the PET study should be 10 days, if possible, or probably as close to the next treatment administration as possible.
Date at which the results of the PET or PET/CT study must be available.
Ability of the patient to lie still in the PET or PET/CT system for the duration of the examination (20–45 min)
History of claustrophobia
Ability to put his/her arms over the head
Precautions
See Society of Nuclear Medicine Procedure Guidelines for General Imaging Version 3
Radiation exposure
The radiation dose with PET/CT or PET is the combination of the radiation exposure caused by the radiopharmaceutical and the CT study (or the external transmission sources). Radiation dose of diagnostic CT has been a matter of debate over the last years, particularly for paediatric examinations. It is difficult to state a mean dose for a CT scan because of the variety of applications, protocols, and CT systems. Especially for children but also for adults it is of importance to optimise the radiation exposure with respect to the diagnostic question. In recent years there has been much effort to minimise the radiation dose related to a conventional CT-or PET examination.
The radiation dose of FDG is approximately $2 \times 10{-}2$ mSv/MBq according to ICRP publication 106 [28], i.e. about 3–4 mSv for an administered activity of 185 MBq. The radiation exposure related to a CT performing a PET/CT examination depends on the intention of the CT carried out and may differ from case to case: the CT can be performed as a low-dose CT (with lower voltage and current) to be used for attenuation correction and localisation of PET lesions. Alternatively (or additionally) a diagnostic CT can be indicated (in most cases with intravenous contrast agent application and deep inspiration in case of a chest CT) for a full diagnostic CT examination. The effective CT dose could range from 1 –20 mSv and may be even higher for a high resolution diagnostic CT scan. Given the variety of CT systems and protocols the radiation exposure for a PET/CT examination should be estimated specific to the system and protocol being used and an expert from radiology or guidelines provided by the European radiological societies should be consulted regarding effective dose from the CT examination.
The choice of the imaging protocol used strongly depends on the clinical question and must be discussed for every single case. In this respect, special attention is required in case of paediatric applications. For the optimisation of PET/CT examinations, dose reduction techniques should be considered.
Performing the PET/CT study
Preparation and execution
In case of manual administration:

– An indwelling intravenous device is used to administer the FDG intravenously once the patient's blood glucose has been determined and blood samples for laboratory testing have been taken if necessary. Make sure that if there is a needle on the syringe it is free from FDG.
– Flush and rinse out the administration syringe with at least 10 ml of normal saline (Na Cl 0.9%) using the three-way valve.
In case of automated administration:
– Make sure that the automated system and procedures assures a net administered FDG activity within 3% accuracy (this must be ensured by manufacturer and verified by the user), i.e. the actual administered activity may not deviate more than 3% from that indicated by the reading of that device or used dose calibrator. Follow instructions given by the manufacturer.
The administration system can be removed after intravenous administration (unless CT contrast agent is to be administered subsequently by intravenous injection).
The ambient conditions in the waiting room must be relaxing and warm. Give the patient extra blankets if necessary.
Tell the patients to lie or sit as calmly as they can, and not to talk. Provide comfortable beds or chairs. They may go to the toilet while waiting, preferably after the first 30 min p.i. Ask the patient to use the bathroom 5 min before the start of the PET study.
An intense bladder or ureteric activity concentration can impair the interpretation of lesions in the pelvis and retroperitonium.
Hydration and loop diuretics (e.g. frusemide i.v.) may be used to reduce bladder activity and radiation exposure to the bladder. Therefore, during the waiting period, patients will be asked to drink another half a litre of water, or this amount can be given in the form of physiological saline intravenously, if such fluid load is not medically contra-indicated. This is of course dependent on the patients other clinical conditions, e.g. impaired renal function or poor cardiac function, where this amount of fluid may be contraindicated.
The recommended interval between FDG administration and the start of acquisition is 60 min. However, for certain clinical trials this may change depending on the disease and aims of the study. This should then be clearly stated in the study protocol. The actual interval should be recorded, i.e. the time of FDG injection (administration) should be reported. Please be aware that this is usually not equal to the FDG activity assay or calibration time. Note that consistency of SUV measurements (in-house and compared with literature) depends on strict application of the interval schedule and therefore a 60-min interval is recommended. When repeating a scan on the same patient, especially in the context of therapy response assessment, it is essential to apply the same interval (tolerance ±5 min). In addition, use of the same PET or PET/CT system and identical acquisition and reconstruction settings must be applied when making multiple scans of the same patient.
Scan trajectory: for most oncology indications, a wholebody scan is sufficient. A 'whole-body' uptake normally covers the part of the body from the mid-femora to the external auditory meatus (in that direction, as bladder activity increases during the scan). A longer scanning trajectory may be used if appropriate. Wholebody PET/CT offers the opportunity for whole-body staging/re-staging. For most oncology indications, skull base-to-mid thigh tumour imaging is sufficient. Extended whole-body examinations are performed in tumours that show a high probability of metastases in the head, skull, brain, cranium, and in the lower extremity.
Limited-area tumour imaging can be considered for follow-up examinations, if the disease is restricted to a defined region (i.e. solitary pulmonary nodule, suspicion of lung cancer, examination of hilar lymph nodes, head and neck tumours, assessment of therapy response). It

should be noted that the entity “effective dose” does not necessarily reflect the radiation risk associated with this nuclear medicine examination. The effective dose values given in this guideline are used to compare the exposure due to different medical procedures. If the risk associated with this procedure is to be assessed, it is mandatory to adjust the radiation-associated risk factors at least according to the gender and age distribution of the institution’s patient population.
The patient should be positioned with the arm elevated over the head to avoid beam hardening artefacts as well as artefacts caused by truncation of the field of view.
For the examination of head and neck tumours, a two step protocol is recommended (head and neck portion and from the apex of the lung through mid thigh) with the appropriate acquisition and reconstruction parameters adapted for the protocol. Alternatively, the arms can be positioned along the side for head and neck imaging.
If the FDG PET/CT data are used for radiation planning, the examination should be carried out in the radiation position using the same dedicated radio-opaque positioning devices as used in the radiotherapy department (e.g. same table tops, laser alignment, immobilisation measures, etc.).

Scan acquisition depends on various factors, including the system type and acquisition mode (2D, 3D). For CT settings in case of PET/CT, CT whole-body or low-dose CT, see other acquisition parameters, CT-protocol. Transmission scanning time for each bed position depends on whether the scan is a CT scan or a transmission scan with Ge-68/Ga-68 source.

In general, PET/CT is carried out using a protocol comprising a scanogram/scout scan/topogram and a low-dose CT for attenuation correction (CT-AC) and anatomical correlation. IV contrast agent must not be administered during the low-dose CT, used for attenuation correction purposes, because of its potential influence on SUV calculation.

In the case of single slice or dual-slice CT, artefacts are created in the diaphragm area when the patient breathes. The patient must therefore hold his/her breath for a few seconds on the technologist’s instructions during CT-AC acquisitions. No such instructions need be given in the case of PET/CT systems with more than two slices. The CT-AC scan can then be carried out while the patient continues to breath shallowly.

A standard diagnostic CT scan with (i.v.) contrast agent may, if appropriate, be carried out according to standard radiological methods after the low-dose CT and PET acquisition in case quantification of the PET study will be performed or is required.

Recommendations for FDG activities are based on assuming fixed scan duration of 5 min per bed position and a bed overlap of less than 25%.
In the case of 2D scans: ca. 5 MBq/kg body weight (±10%).
In the case of 3D scans: ca. 2.5 MBq/kg body weight (±10%).
Permitted protocol alterations regarding FDG activity detailed recommendations and permitted alterations of the administration protocol are given, including those for systems that apply a 50% bed overlap.
For children (<19 years), FDG activity must conform to the EANM recommendations given in the EANM paediatric dosage card [29].

Specifications of transmission scans based on a Ge-68 line source: >2 min per bed position. In paragraph Other acquisition parameters, CT-protocol, recommendations are given for the CT-AC.
Permitted protocol alterations regarding FDG activity When using systems with a high count rate capability (LSO, LYSO, and GSO-based cameras with or without time of flight), the administered FDG activity and scan duration for each bed position must be adjusted so that the product of the FDG activity and scan duration +10% is equal to or greater than the specifications set out below. Therefore, one may decide to apply a higher activity and reduce the duration of the scan or, preferably, use reduced activity and increase scan duration, thereby keeping ALARA principles in mind as well.
The figures for systems with bed overlap of<25% are:
– Product of MBq/kg × min/bed>27.5 for 2D scans
– Product of MBq/kg × min/bed>13.8 for 3D scans.
The dosage is then calculated as follows:
– FDG activity in MBq for 2D scans=27.5 × weight/
(min/bed)
– FDG activity in MBq for 3D scans=13.8 × weight/
(min/bed)
And for systems with a bed overlap of 50%:
– Product of MBq/kg × min/bed>6.9 (3D only)
– FDG activity in MBq=6.9 × weight/(min/bed)
The specifications indicate that heavier patients receive a higher FDG activity. A short scanning duration per bed position should also be offset by a higher FDG activity [3, 30]. Two model calculations are given in`Appendix I to clarify the situation.

For obese subjects (>90 kg), increase of scanning time (time per bed position) rather than increase of FDG activity is recommended to improve image quality. A recent publication suggests that FDG activities higher than 529 MBq for patients above 90 kg should not be applied for LSO systems [31]. Therefore, it is recommended to keep administered activity below 530 MBq.
A maximum allowed FDG activity may be imposed by national law. In the latter case, increase of scanning time should be applied to keep FDG activity within legal limits.
If the scanning duration for each bed position can be set separately, then the scanning duration per bed position may be further reduced by up to 50% for bed positions outside the thorax and abdomen (i.e. at the level of the head, neck and legs, as attenuation is less). The FDG activity must still be calculated assuming the scanning duration per bed position as used for bed positions at the level of the thorax and the abdomen.
In all cases the administered activity should not result in count rates above the count rate capability of the PET or PET/CT system being used. Increase of scan duration should then be applied to improve image quality.
Other acquisition parameters
Emission scans:
Online randoms correction should be based on ‘delayed coincidence time window’ technique or randoms correction using a model based on (block) singles count rates
Indication of the correct isotope, the patient’s height and body weight, and the FDG activity administered. Please also note and report assay activity (=FDG activity) and assay time

(=activity calibration time). In addition, indicate time of injection (usually not equal to assay time or activity calibration time) should be noted and reported.
Decay correction must be ‘on’ (see also “Image reconstruction”).
CT-protocol
The CT in the framework of a PET/CT examination comprises the topogram and the helical CT scan.
If a CT is solely performed for attenuation and scatter correction and co-localisation, the acquisition parameters (tube current, voltage, slice thickness, rotation time, and pitch) should be selected in order to minimise the radiation exposure for the patient.
For a diagnostic contrast-enhanced CT, standard CT milliampere-seconds settings or those given by the radiological societies/radiologist should be used. The modulation of the tube current can be used to lower the radiation exposure of the patient. Depending on the clinical question, intravenous and/or oral contrast agents may be used. It might be useful to perform a diagnostic CT only for portions of the body, whereas for the rest of the body a low-dose CT is performed for attenuation correction and co-localisation. High intravenous concentrations of contrast material may cause artefacts on the reconstructed PET image and affect quantification and should thus not be applied during the CT-AC in case quantification (i.e. SUV) is performed (but may be used after concluding the PET/CT examination during an additional diagnostic CT). In the case of PET/CT scans without need for quantification, intravenous contrast agents may be used directly (i.e. this CT may also be used for attenuation correction purposes) during the PET/CT study because the impact on visual image quality and interpretation is modest. However, deep inspiration at chest CT will obviously cause misregistration and artifacts if low-dose CT (with normal breathing) is replaced by such a diagnostic deep inspiration CT.
Oral contrast agents allow a better delineation of the gastrointestinal tract. Positive contrast material (like diluted barium) as well as negative contrast material (for example water) can be used. High intraluminal concentrations of barium or iodinated contrast agents can cause an attenuation correction related artefact in the PET images resulting in an overestimation of FDG accumulation at those sites. These artefacts can be avoided by using negative contrast agents. However, administration of water only as negative intraluminal contrast agent itself is associated with a fast resorption and can cause increased nonspecific FDG accumulation in the bowel. In case quantification of the PET/CT studies is required, it is recommended to use diluted positive contrast agents only. The concentration of diluted positive contrast agents should be low enough to guarantee absence of attenuation correction artefacts, which should be verified for each combination of PET/CT system, PET/CT image reconstruction software and contrast agent being used.
Ensure that the patient is lying within the CT-AC field of view (FOV) and in the same position as during emission scanning.
Pitfalls
In some PET/CT systems, the FOV of the CT and CTAC is smaller than that of the PET. Truncating the CT (and CT-AC) causes reconstruction artefacts and therefore inaccurate quantification of the PET scan. When available, truncation corrections algorithms may be applied during image reconstruction (and/or during processing of CT used for attenuation correction). However, one needs to demonstrate that quantification is not affected by CT truncation even when truncation corrections are applied. As the amount of truncation may vary across scans and subjects, it will be difficult to ensure proper quantification across scans and subjects. It is therefore strongly recommended to avoid any CT truncation. It should be noted

that CT truncation may occasionally seriously affect the scatter correction and may lead to non-quantitative results.
When using Ge-68 transmission sources, they must be replaced on time (i.e.,: at least once every 18 months) and/or following the manufacturer's recommendations. It is recommended to compensate for the decay of transmission scan sources over time by increasing transmission scan durations, e.g. by performing transmission scans based on total number of collected counts, if possible [32].
Make sure that all clocks (of dose calibrator and PET or PET/CT system) are synchronized. Consult your local service engineer when needed. Clocks should be synchronised with the official local time within 1 min (in case of FDG studies).

Image reconstruction

PET image reconstruction

The PET emission data must be corrected for geometrical response and detector efficiency {normalisation), system dead time, random coincidences, scatter, and attenuation. Some of these corrections (for example attenuation correction) can be directly implemented in the reconstruction process. In all cases, all corrections needed to obtain quantitative image data should be applied during the reconstruction process. Data acquired in the 3D mode can be reconstructed directly using a 3D-reconstruction algorithm or rebinned in 2D data and subsequently be reconstructed with a 2D-reconstruction algorithm. Iterative reconstruction algorithms represent the current standard for clinical routine and have meanwhile replaced filtered backprojection algorithms for PET reconstruction. It is good clinical practice to perform reconstructions with and without attenuation correction to tackle potential reconstruction artefacts caused by a CT-based attenuation correction. For clinical cases, reading the reconstructed 3D volume data set is visualized in transaxial, coronal, and sagittal slices, but also the maximum intensity projections should be available. Further standardisation of reconstruction settings is necessary in order to obtain comparable resolutions and SUV recoveries and make SUVs interchangeable, i.e. reconstructions are chosen such to achieve convergence and resolution matching across various PET and PET/CT systems and sites, especially within a multi-centre setting [15, 30, 33]. However, also for clinical practice, strict standardisation is needed to provide the same quality of care across sites and to allow for exchange and use of quantitative PET information elsewhere. Some indicative reconstruction settings are suggested in Appendix II. However, most importantly, reconstructions should be chosen so that they meet the multi-centre QC specifications for both calibration QC and image quality/SUV recovery QC, as described in "Quality control and inter-institution cross-calibration".

Exceptions/special features

Various new types of cameras are coming into the market. It is not yet possible to specify rational dosage, acquisition, and reconstruction specifications for them. Moreover, default reconstruction settings may change over time. Therefore, institutions may deviate from the recommended/prescribed dosage and acquisition protocol if it can be demonstrated that the alternative protocol provides equivalent data. The convergence and overall final image resolution must also match this study protocol QC specification. Compliance with these requirements must be demonstrated by means of the tests described under Quality Control and inter-institution crosscalibration in "Quality control and inter-institution crosscalibration".
Calibration and activity recovery coefficients may not deviate from multi-centre standard specifications by more than 10%. These specifications are given in "Quality control and inter-institution cross-calibration". In other words: any combination of acquisition and reconstruction

protocol and/or settings which meets the multi-centre QC specifications given later and especially those for the (absolute) activity (or SUV) recovery coefficients is allowed.

CT image reconstruction

The CT data that are acquired during the PET/CT scanning session are usually reconstructed by use of filtered back projection or a similar algorithm. Depending on the CT protocol and the diagnostic question separate CT reconstructions for the PET attenuation correction and for the diagnostic CT are performed. The reconstructions differ in their slice thickness, slice overlap, filter, etc. In addition to the reconstruction kernel that modulates the image characteristics within the slices (i.e. spatial resolution, edge enhancement and noise texture), a longitudinal filter in the z-dimension is used to optimise the resolution in the z direction and to modify the slice-sensitivity profiles. The measured attenuation values are normalized to the density of water in order to assign a device-independent numeric value in the framework of the reconstruction. CT _ value ¼ HU ¼ 1000ðm _ m waterÞm water

This procedure additionally reduces the dependency of the attenuation values from the radiation energy. In modern CT tomographs, the spatial resolution in the z-dimension is almost as high as the transaxial resolution and almost isotropic allowing image visualisation in coronal and sagittal views in a high quality. Additionally, post-processing like volume rendering or maximum intensity projections (MIPs) benefit from the high quality of the raw data.

Reporting

Reporting PET findings and SUV calculations

The reconstructed PET and CT images are assessed from a computer screen. The software packages for current PET/CT systems enable visualisation of PET, CT, and PET+CT fusion images in the axial, coronal, and sagittal planes as well as maximum intensity projections in a 3D cine mode.

FDG PET images can be displayed with and without attenuation correction. On all slices (of the attenuation corrected data) quantitative information with respect to size and FDG uptake can be derived. Images must be evaluated using software and monitors approved for clinical use in radiology and nuclear medicine. Characteristics of monitor and settings should be in line with published standards (e.g. the Medical Electrical Safety Standards (IEC 60601-1/EN 60601-1), the Medical ECM Standards (IEC 60601-1-2, EN 60601-1-2) or national guidelines). Moreover, environment conditions (background light) must be at appropriate levels to ensure adequate image inspection.

The presence or absence of abnormal FDG accumulation in the PET images, especially focal accumulation, in combination with their size and intensity are evaluated. Absence of such accumulation is particularly significant if other tests have revealed findings such as anatomical abnormalities. Where necessary, the report correlates these findings to other diagnostic tests and interprets them in that context (in consultation with a radiologist where necessary) and considers them in relation to the clinical data. For response assessment, the images should be viewed over the same dynamic grey scale or colour scale range, i.e. a fixed colour scale e.g. from SUV=0 to 10 is recommended. Both uncorrected and attenuation-corrected images need to be assessed in order to identify any artefacts caused by contrast agents, metal implants and/or patient motion. Criteria for visual analysis must be defined for each study protocol. Standardized uptake values are increasingly used in clinical studies in addition to visual assessments. SUV is a measurement of the uptake in a tumour normalized on the basis of a distribution volume. It is calculated as follows:

SUV ¼ ActvoiðkBq=mlÞActadministeredðMBqÞ=BWðkgÞ

The following calculation is applied in the case of plasma glucose correction
SUVglu ¼ ActvoiðkBq=mlÞActadministeredðMBqÞ=BWðkgÞ_
Glucplasmaðmmol=lÞ5:0ðmmol=lÞ
In these calculations, Actvoi is the activity measured in the volume of interest (see "Definitions for volumes of interest (VOI) and regions of interest (ROI)"), Actadministered is the administered activity corrected for the physical decay of FDG to the start of acquisition, and BW is body weight. Patient height, weight, and gender should be reported to allow for other SUV normalisations (LBM, BSA). The latter is of importance to meet EORTC recommendations [13] and, for response assessment studies, when large changes in body weight occur during the course of the treatment. As stated earlier, it is recommended to measure plasma glucose levels using validated methodology and calculate SUV with and without plasma glucose correction in all response monitoring assessment studies ("Patient preparation", extra notes). Note that the measured glucose content (Glucplasma) is normalised for an overall population average of 5.0 mmol/l so that the SUVs with (SUVglu) and without (SUV) correction of glucose content are numerically practically identical (on average) [3].

Interpretation and pitfalls

Interpretation criteria

A physiological and variable FDG accumulation can be observed to a certain degree in most viable tissue: brain, myocardium (in which the FDG accumulation can be high in the fasting state), breast, liver, spleen, stomach, intestine, kidneys, urine, skeletal muscle, lymphatic tissue, bone marrow, salivary glands, thymus, uterus, ovaries, testicles, and brown fat.

In whole-body PET/CT examinations the brain shows a high FDG accumulation. For the detection of brain metastases FDG PET is therefore only of limited value.
In consequence FDG PET is usually not used for the primary detection or exclusion of brain metastases.
An increased FDG uptake is observed in neoplastic lesions, granulation tissue (e.g. wound healing), infections and other inflammatory processes.
Patterns of FDG uptake, established CT-morphological criteria as well as correlation with patient history, physical examination and other imaging modalities may be helpful for the differentiation between malignant and benign lesions. Semi-quantitative parameters (for example SUV) gain increasing importance for therapy response monitoring and for assessing the prognosis of patients.
Detection limits obviously depend on the degree of contrast between the tumour and its immediate surroundings.
Sensitivity of FDG PET is much lower in diabetic patients. There is no single detection limit for FDG PET since it depends on many factors. The most significant of these are: histology (FDG avidity of the type of tumour), the volume of vital tumour cells, movement during acquisition (e.g. blurred signals in the case of pulmonary foci), and physiological uptake in the adjacent background. Although it is impossible to give universal rules for detection limits, it has been demonstrated that even in the case of tumours that take up FDG in large amounts, such as melanoma, the sensitivity of FDG PET declines when the diameter of the tumour is less than 6 mm. Non-specific, nonphysiological uptake is based on inflammatory processes or uptake in brown fat (neck, upper mediastinum, paravertebral region). In patients who have undergone surgery, uptake therefore depends on the extent of surgery and how far the wound has healed: for example, there are few visible signs of a mediastinoscopy after ten days but a sternotomy will

remain visible for months. The resolution of FDG PET for bone fractures is more or less the same as has been established for skeletal scintigraphy.

Additional remarks

Though there are no conclusive data on the optimum interval between chemotherapy and PET, an interval of at least 10 days is generally considered between the last treatment and PET. This is because of any possible effects on tumour metabolism (such as macrophage impairment) and systemic effects (such as bone marrow activation following bone marrow depression, which may or may not be caused by growth factors). The effects of growth factors (Gm-CSF) or FDG biodistribution (due to enhanced bone marrow uptake) do not last for more than 2 weeks after the final administration. It is assumed that the effects of radiotherapy are somewhat longer lasting; investigation of cases of laryngeal carcinoma treated by radiation has shown that due to radiation-induced inflammation, it is best to wait for about 3 months after the end of treatment before conducting FDG PET. This timing fits well into this clinical context as these patients rarely develop clinical problems in the first 3 months after treatment.

FDG PET is generally assessed using visual criteria (in the context of oncology, looking for a focally increased uptake that may be compatible with malignancy in the clinical context. It is unclear how far semi-quantitative measurements such as SUV can contribute to the assessment, partly because of the considerable variability in the methodology used [30, 33]. This recommendation is an attempt to increase uniformity of FDG PET investigations in multi-centre studies and for routine clinical applications. It is therefore also essential that the equipment used is comparable. This can be achieved by means of (cross-) calibration, as described in "Quality control and inter-institution cross-calibration".

Documentation and report

Examination label

Clinical information:

– Indication for PET/CT-examination

– Relevant patient history

– Information relevant for reimbursement

PET/CT-Examination and imaging protocol

– Radiopharmaceutical with applied activity, purity, injection type and site (localisation of injection), time of injection, uptake time, body weight (for each longitudinal study) and height, gender

– Information concerning medication administered as preparation of the PET scan

– Field of view and patient positioning: whole-body

PET/CT, skull base to mid thigh, limited area and position of the arms

– Blood glucose level before the examination and used methodology to obtain blood glucose

– CT-protocol: low-dose or/and diagnostic CT, contrast agent application (oral, intravenous, information on concentrations and volumes, native, arterial, portal venous), scanned portion of the body

Clinical report

– Quality of the PET/CT-examination: i.e. limited due to motion artefacts, FDG accumulation in muscles and/or brown fat, hyperglycemia, CT-related artefacts, high patient body weight

– Description of the localisation, the extent and the intensity of pathological FDG accumulations related to normal tissue. Description of relevant findings in CT and their relation to pathological FDG accumulations. FDG accumulation should be reported as mild, moderate, or intense and compared to the background uptake in e.g. the liver parenchyma (mean SUV: 2.0–3.0; maximum

SUV: 3.0–4.0). However, criteria for visual interpretation must be defined for each study protocol and/or type of cancer because they may differ for different tumour locations and types. Some criteria have already been proposed [7, 34]. The CT part of the PET/CT report must described all findings (even in the case they are PET negative), and exception being that the CT is only used for attenuation correction.

Limitations: If necessary, confounding factors influencing sensitivity and specificity of the PET/CT examination should be noted: small lesions (partial volume effect), inflammatory changes, muscle activity, high blood glucose levels at the time of injection

Clinical context: Addressing the findings with respect to the clinical questions asked in the context of the PET/CT examination
Complementary information: Comparison with previous examinations should be part of the PET/CT report. PET/CT examinations are more valuable, if they are interpreted in the context of results of other imaging examinations (for example CT, PET, PET/CT, MRI, etc.) and relevant clinical data. If a PET/CT examination is performed in the context of the assessment of response to a therapy the extent and the intensity of the FDG uptake should be documented. The European Organisation for Research and Treatment of Cancer (EORTC) has published criteria for the assessment of therapy response with FDG as metabolic marker. The documentation of a change in intensity of the FDG accumulation with semi-quantitative parameters—expressed as absolute or relative change—can be used for dedicated clinical questions. At present, relative changes in SUV under therapy represent the most robust parameter. A focus must be put on the equivalence of the results achieved with respect to comparability of technical protocols and data analysis.

Summary and diagnosis
– If possible, a definite diagnosis should be stated whenever possible. Alternatively, an estimate of the probability of a diagnosis should be given.
– If relevant, differential diagnoses should be discussed
– If appropriate, repeat examinations and/or additional examinations should be recommended to clarify or confirm findings.
For further reading, also see the Society of Nuclear Medicine Procedure Guidelines for General Imaging.
Definitions for volumes of interest (VOI) and regions of interest (ROI)
Definition:
The maximum SUV measure (SUV max) is required for each lesion as specified in the study protocol and/or as considered clinically relevant. The voxel with maximum uptake should be determined as follows:
– This volume of interest equals the voxel with highest uptake in tumour/lesion. The maximum uptake should be defined on original reconstructed PET images, i.e. no additional rebinning, resampling, smoothing by the user is allowed.

(For detailed specifications regarding individual PET/CT systems and Bibliography refer to EANM procedure guideline for tumour PET imaging: version 1.0)