Concurrent PET/CT with an Integrated Imaging System: Intersociety Dialogue from the Joint Working Group of the American College of Radiology, the Society of Nuclear Medicine, and the Society of Computed Body Tomography and Magnetic Resonance

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Rapid advances in imaging technology are a challenge for health care professionals, who must determine how best to use these technologies to optimize patient care and outcomes. Hybrid imaging instrumentation, combining 2 or more new or existing technologies, each with its own separate history of clinical evolution, such as PET and CT, may be especially challenging. CT and PET provide complementary anatomic information and molecular information, respectively, with PET giving specificity to anatomic findings and CT offering precise localization of metabolic activity. Historically, the acquisition and interpretation of the 2 image sets have been performed separately and very often at different times and locales. Recently, integrated PET/CT systems have become available; these systems provide PET and CT images that are acquired nearly simultaneously and are capable of producing superimposed, coregistered images, greatly facilitating interpretation. As the implementation of this integrated technology has become more widespread in the setting of oncologic imaging, questions and concerns regarding equipment specifications, image acquisition protocols, supervision, interpretation, professional qualifications, and safety have arisen. This article summarizes the discussions and observations surrounding these issues by a collaborative working group consisting of representatives from the American College of Radiology, the Society of Nuclear Medicine, and the Society of Computed Body Tomography and Magnetic Resonance.

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PROLOGUE

The introduction of any new technology presents challenges that are sometimes unsettling. The issues become even more interesting when 2 established technologies with different underlying methodologies are hybridized into 1 instrument, such as the recent introduction of in-line PET/CT. In this setting, sensitivities become increasingly acute when previously established patterns of patient care and professional expertise are challenged. In many instances, some people feel abruptly disenfranchised when confronted by a device with which they are only partially familiar and less than expert. Further, there are the inevitable quandaries regarding which patients are best served, optimum imaging protocols, who will perform and supervise examinations, who will interpret results, and the most efficient, cost-effective manner in which to use the technology while preserving excellence in patient care. What education is needed to interpret that portion of the examination with which an imaging physician has had little or no training or recent experience? How can such expertise be acquired? The queries are myriad, and the answers are untested or uncertain.

In response to these issues raised by their members, the American College of Radiology (ACR), the Society of

Nuclear Medicine (SNM), and the Society of Computed Body Tomography and Magnetic Resonance (SCBT/MR) have sponsored a joint working group of experts in PET and body CT with experience in PET/CT to define the issues surrounding the implementation and use of PET/CT in the service of oncology patients and to offer thoughts regarding possible solutions when appropriate. After working on this project for almost a year, the members of this working group have assembled their deliberations in this article. The intent of this intersociety dialogue is to serve as a starting framework for expanding relevant discussions among the members of the participating societies as well as in the broader imaging community. The content of the intersociety dialogue consists of a combination of fact, informed opinion, and speculation. It is not intended in any way to be the final analysis or last word on the issues addressed. It must be emphasized that the preliminary conclusions of this article have not been endorsed as policy by the sponsoring professional societies, which simply facilitated the PET/CT colloquium at the request of and as a service to their members and the patients they serve. However, any eventual broad consensus arising from the ensuing dialogue likely will influence future codifying documents, such as practice guidelines and accreditation procedures. It should be noted that this report is limited to the diagnostic uses of PET/CT and does not address issues related to the applications of PET/CT in the setting of radiation oncology.

Although this report summarizes a dialogue of representatives from the Joint Working Group of the ACR, the SNM, and the SCBT/MR (Appendix A), PET/CT technology is new, and some issues remain poorly defined and controversial. The protocol options used for CT performed concurrently with PET are multiple and range from only an anatomic localization study with limited radiation dose to the patient to a diagnostic CT protocol with oral and intravenous contrast materials. Various CT protocols are available, and it is not possible to define clearly a line at which CT is used for diagnostic purposes versus anatomic localization purposes only.

One goal of the working group was to determine the amount of on-the-job training needed in PET to allow radiologists and nuclear medicine physicians without PET experience to supervise and interpret PET scans obtained on a PET/CT scanner. A second goal was to determine the amount of on-the-job training needed in CT to allow radiologists without recent CT experience or nuclear medicine physicians to supervise and interpret scans from CT performed concurrently with PET regardless of the protocol used. There was less controversy related to the proposed amount of on-the-job training needed in PET than in CT. The group was divided in this respect by the lack of a firm consensus with regard to what amount of training is needed to permit the interpretation of diagnostic CT scans in the context of PET/CT, separate from the use of CT scans for anatomic localization. Some members agreed with the concept that the on-the-job training in CT presented in the proposal should allow a trainee to supervise and interpret scans from CT performed concurrently with PET regardless of the protocol used. The justifications for this position were that the interpretive responsibility and liability are similar regardless of the CT protocol used and that there currently is no clear definition of the protocol for diagnostic CT in the setting of PET/CT.

All of the societies collaborating on this document agreed that the on-the-job training described here is minimum training for the interpretation of PET/CT for anatomic localization. However, the ACR is concerned that as the standard for the CT component of PET/CT is evolving rapidly to a full diagnostic, contrast-enhanced CT examination, allowing the performance of and interpretation of scans from diagnostic CT with the on-the-job training proposed in this document is in conflict with current ACR practice guidelines previously published for nonradiologists interpreting CT scans and may not be sufficient to permit the expert supervision and interpretation of such studies. These existing ACR guidelines, written and adopted before the advent of PET/CT, recommend "completion of an accredited residency in the specialty practiced plus 200 h of category I continuing medical education (CME) credit in the performance and interpretation of CT in the subspecialty in which reading CT occurs and 500 cases interpreted and reported in the past 36 months in a supervised situation." The 6 subspecialties defined in the ACR guidelines are neuroradiology/head and neck, musculoskeletal, chest, cardiovascular, abdominal and gastrointestinal, and genitourinary. From the ACR perspective, PET/CT scan interpretation in the oncologic setting may involve any or all of these subspecialties. Thus, proposed training could be considerably more extensive than that described in this document. Therefore, the ACR has neither approved nor endorsed the training requirements proposed in this document for the interpretation of diagnostic CT scans. However, both the ACR and the SNM support the publication of this document to promote discussions of these very important issues.

Some discussions are ongoing regarding the need for practice guidelines for new combined technologies as embodied by PET/CT instead of the application of existing but separate practice guidelines for PET and CT promulgated before the development of PET/CT.

Such guidelines would provide an opportunity to properly assess and acknowledge the correlative experience of imaging physicians in the complementary modality in which they have not been formally trained. Despite the concerns and differences in opinion, there is a strong desire from all of the parties involved, as imaging specialists with genuine concerns for patient care and professional responsibility, to continue collaboration and define common practice guidelines in the future.

It is hoped that the collaborative PET/CT proposal will succeed in its purpose of stimulating thoughtful and honest discussions of the important issues that it outlines. The imaging community deserves no less.

INTRODUCTION

Brief History

Rapid advances in imaging technologies are a challenge for health care professionals, who must determine how best to use these technologies to optimize patient care and outcomes. Since the early 1970s, numerous technologic improvements have occurred in the field of medical imaging. These include CT, MRI, and PET. Since its development in the early 1970s, CT has become the standard of care for the evaluation of patients with malignancies because of its excellent definition of anatomic details. The slip ring technology and faster computer systems have laid the foundations for helical data acquisition, allowing fast volumetric scanning and multiphase enhancement techniques. State-of-the-art multislice helical CT permits fast acquisition of volumetric and CT angiographic images. The anatomic definition of organs is also very good with MRI, which is commonly used for better characterization of lesions and for patients allergic to the iodinated contrast agents used with CT. The advancements in MRI (e.g., fast acquisition protocols with multiple new pulse sequences and new MRI contrast agents) are beyond the scope of this review. PET with various radiopharmaceuticals provides molecular information but limited anatomic details. Clinical research in PET lasted for many years before reimbursement finally was approved for limited applications in 1998. The early clinical applications of PET emerged in the early 1980s in the field of neurology, in the early 1990s in cardiology, and in the late 1990s in oncology. It was not until the late 1990s that PET with ^{18}F-FDG as the radiopharmaceutical began to be used widely in the clinical setting for the evaluation of oncology patients.

The clinical utility of ^{18}F-FDG imaging was first established by use of dedicated PET scanners typically equipped with multiple rings of bismuth germanate detectors. A spectrum of equipment is now available for PET: state-of-the-art PET/CT systems with bismuth germanate–based PET systems as well as other PET systems with other detector materials, for example, lutetium oxyorthosilicate and gadolinium oxyorthosilicate.

The oncologic applications of PET, including the differentiation of benign lesions from malignant lesions, the staging of malignant lesions, the detection of cancer recurrence, and monitoring of therapy, have led to the establishment of PET technology in many medical centers in the United States, in Europe, and progressively throughout the world. The goals of oncologic imaging are lesion detection, lesion characterization, staging of malignant lesions, and assessment of the therapeutic response. Staging includes lesion localization, evaluation of proximity to vessels, and detection of nodal and distant metastases. Some of these goals are better achieved with high-resolution anatomic imaging techniques, and others are better achieved with molecular imaging by PET.

Molecular imaging by PET is unique in that positron-emitting radionuclides can be incorporated into radiopharmaceuticals that closely mimic endogenous molecules, and there are continuing efforts to develop new biologic tracers. The radiopharmaceutical that is most widely used with PET technology is the glucose analog ^{18}F-FDG.

Desirability of Anatomic and Functional Imaging

Although numerous studies have shown that the sensitivity and specificity of ^{18}F-FDG imaging for tumor detection are superior to those of CT in many clinical settings, the inability of ^{18}F-FDG imaging to provide anatomic localization remains a significant impairment in maximizing its clinical utility. Close correlation of ^{18}F-FDG studies with conventional CT scans helps to minimize these difficulties. The interpretation of patient studies when both PET and CT have been performed has been accomplished by visually comparing corresponding images. Software fusion techniques are available and have been used for the head but have limitations for the body compared with hardware fusion techniques. Another approach that has gained wide acceptance is the hardware approach to image fusion—multimodality imaging with an integrated PET/CT system (1).

PET/CT DEFINITIONS AND TERMINOLOGY

Basic Principles

The recent development of integrated PET/CT systems allows CT and PET images to be obtained in a single imaging setting and provides optimal coregistration of images. The fusion images provided by these systems allow the most accurate interpretation of both CT and PET studies. Integrated PET/CT is also a promising tool for optimizing radiation therapy and guiding biopsy. Because of the high photon flux of x-ray beams, CT attenuation maps from these integrated PET/CT systems also allow for optimal attenuation correction of the PET images and shorter acquisition times.

With these integrated systems, a diagnostic CT scan and a PET scan can be acquired sequentially with the patient lying on the imaging table and with simple translation between the 2 systems. Accurate calibration of the position of the imaging table and the use of common parameters in data acquisition and image reconstruction permit the fusion of images of anatomy and metabolism that are from the same region of the body and that are registered in space and only slightly offset in time.

Technology Overview

The first prototype of an integrated PET/CT system was developed in collaboration with a group of investigators at the University of Pittsburgh (1,2). Several manufacturers are now offering integrated PET/CT systems combining different models of dedicated PET scanners and multislice CT scanners in line with a common imaging bed.

CLINICAL INDICATIONS IN ONCOLOGY

Strengths and Limitations of Techniques

An optimized diagnostic CT scan usually is performed after the bolus administration of an intravenous contrast agent to improve the delineation of vascular structures and to improve both the detection and the characterization of lesions. Oral contrast material usually is administered before CT of the abdomen and pelvis for better delineation of the gastrointestinal tract and to differentiate bowel from lymph nodes or masses. CT protocols have been optimized for tumor detection, with respect to slice thickness, scan speed, timing of acquisitions, and injection rates. Limitations of anatomic imaging with CT are well known and relate to the use of size criteria to differentiate benign lymph nodes from malignant lymph nodes, difficulty differentiating posttherapy changes from tumor recurrence, and difficulty differentiating nonopacified loops of bowel from primary or metastatic lesions in the abdomen and pelvis.

^{18}F-FDG is an analog of glucose, and ^{18}F-FDG PET allows the evaluation of glucose metabolism. ^{18}F-FDG enters cells by the same transport mechanism as glucose and is intracellularly phosphorylated by hexokinase to ^{18}F-FDG-6-phosphate (^{18}F-FDG-6-P). In cells with a low concentration of glucose-6-phosphatase, such as those in the brain, those in the myocardium, and most malignant cells, ^{18}F-FDG-6-P does not enter further enzymatic pathways and accumulates intracellularly in proportion to the glycolytic rate of the cells. Most malignant cells have higher levels of glucose transporter proteins and higher levels of glycolytic enzymes than do normal cells and therefore accumulate ^{18}F-FDG-6-P to higher levels than does normal tissue. However, the distribution of ^{18}F-FDG is not limited to malignant tissue. To avoid misinterpretations, the interpreter of ^{18}F-FDG PET scans must be familiar with the normal pattern and physiologic variations of ^{18}F-FDG distribution and with clinical data relevant to the patient concerning conditions that could alter ^{18}F-FDG biodistribution (3,4). In addition, the lack of anatomic landmarks on PET images prevents the accurate localization of ^{18}F-FDG–avid foci of uptake.

Therefore, PET typically is interpreted in correlation with CT. The interpreting physician visually integrates the 2 image sets to locate more precisely a region of increased ^{18}F-FDG uptake on the CT scan.

Indications

Diagnosis, Staging and Restaging, and Therapy Monitoring. A comprehensive review of the ^{18}F-FDG PET oncology literature was published in 2001 to document the excellent performance of this imaging modality in diagnosis, staging, detection of recurrence, restaging, and monitoring of therapy for most malignant tumors (5). The oncologic indications that were approved for reimbursement by Medicare in 2001 included diagnosis, staging, and restaging of non–small cell lung cancer, head and neck cancer, esophageal cancer, colorectal cancer, lymphoma, and melanoma. More indications were approved in 2002 and 2003; these included

staging, restaging, and monitoring of therapy for breast cancer and restaging of thyroid cancer, restricted to patients with tumors of the follicular type, negative ^{131}I scan results, and elevated thyroglobulin levels. More indications are likely to be approved in the future. Because of the inherent limitations of CT and PET performed separately (as described above), the use of PET/CT will continue to grow.

Image-Guided Therapy. PET/CT fusion images have the potential to provide important information for guiding biopsies of the most metabolically active regions of tumors and the potential to provide better maps of viable cancer than does CT alone for modulating the field and dose of radiation therapy (6–8).

PET/CT fusion images from integrated systems have the potential to change the field of radiation therapy. In a group of 39 patients with various extracranial body malignancies scheduled to be treated with radiation therapy, the target volumes measured on CT images alone were compared with those measured on PET/CT fusion images (7). The planned treatment was changed in 56% of patients (22/39) on the basis of PET/CT fusion images. The volume delineation variability between 2 independent oncologists decreased significantly, and the treatment strategy changed from curative to palliative in 16% of patients because of the detection of unsuspected distant metastases.

Benefits of Combined Techniques

Integrated PET/CT (Hardware Fusion) Versus Software Fusion. To aid in image interpretation, computer software has been developed to coregister ^{18}F-FDG PET emission scans with the high-resolution anatomic maps provided by CT (9). These methods offer acceptable fusion images for the brain, which is surrounded by a rigid structure, the skull. For the body, coregistration of 2 images often obtained at different points in time is technically more difficult. Identical positioning of the patient on the imaging table is important. Internal organ movement and peristalsis make accurate PET and CT image fusion problematic when the images have been obtained in different positions and at different points in time.

Integrated PET/CT Systems with Contemporaneous Acquisition Versus Separate PET and CT Acquisitions. Although recent advances in software modeling have produced complex nonrigid algorithms that produce sophisticated image registration for fusion imaging, the limitations related to identical positioning during 2 independent acquisitions at different times and internal organ movement remain a major problem in the application of this technology in the body. However, the coregistration-software approach to fusion imaging allows the production of fusion images from different imaging modalities, for example, PET, CT, MRI, and SPECT.

The literature comparing fusion images provided by integrated PET/CT systems with fusion images generated by coregistration software from independent acquisitions in the same patient is limited.

Attenuation Correction with CT Versus Radioisotope Methods. Because the CT scan is a high-resolution transmission map, these data can be used to perform high-quality attenuation correction during image reconstruction of emission data.

Attenuation effects are much more significant in coincidence imaging than in SPECT because both photons from an annihilation process must pass through the region without interaction. Attenuation correction has significant advantages for the clinical evaluation of ^{18}F-FDG images from oncology patients; the most important of these is improved anatomic delineation (mediastinum from lungs or lungs from liver). Therefore, lesions can be localized more easily on images with attenuation correction. Another advantage of attenuation correction is the ability to measure semiquantitatively the degree of uptake in a lesion by use of the standardized uptake value (SUV), a feature that may be helpful in some clinical settings. Attenuation correction is necessary for accurate quantification of the information in images.

For PET of the body, various methods have been developed for obtaining attenuation measurements with radioactive transmission sources. Measurement of attenuation correction commonly is performed by direct measurement of 511-keV photon attenuation through the body. The transmission scan adds 20–25 min to the length of the study. Furthermore, motion of the patient during long scanning times is a problem because the quality of the image corrected for attenuation effects depends on accurate coregistration of the attenuation map (transmission scan) and the emission scan.

The use of an x-ray tube–based transmission scan (CT) provides attenuation-corrected emission images of high quality because of the high photon flux inherent in this technique. An advantage of CT over the use of radioactive sources is the short duration of the transmission scan; with multidetector CT, a CT acquisition that extends from the base of the skull to midthigh may occur during a single breath hold (10–20 s), versus 20–25 min with a transmission scan performed with external radioactive sources. In addition, optimal coregistration between attenuation maps and emission images is possible with integrated PET/CT systems when CT attenuation maps and ^{18}F-FDG PET images are obtained sequentially in time without moving the patient from the imaging table. An adequate CT transmission scan actually can be obtained with a very low current (10 mA) (*10*). However, higher CT currents are required to produce diagnostic CT scans. A fixed CT current of 80 mA may be used to reduce the radiation dose to patients. The CT current can be adjusted according to the patient's weight and modulated on the basis of the region of coverage (*11*).

Clinical Impact of Integrated PET/CT Images for Anatomic Localization. From the diagnostic point of view, the CT scan obtained for attenuation maps also can be used for the precise localization of foci of ^{18}F-FDG uptake with the help of the fusion of anatomic and molecular images (*12*).

Published data regarding the incremental value of integrated PET/CT images compared with PET images alone or with PET images correlated with CT images obtained at a different time are limited, but available studies have demonstrated the following: improvement of lesion detection on both CT and ^{18}F-FDG PET images; improvement of the localization of foci of ^{18}F-FDG uptake, resulting in better differentiation of physiologic uptake from pathologic uptake; and precise localization of malignant foci, for example, in the skeleton versus soft tissue or in the liver versus adjacent bowel or lymph node.

After performing 100 oncology studies with an integrated PET/CT system, investigators at the University of Pittsburgh concluded that PET/CT images offer significant advantages over PET images alone, including more accurate localization of foci of uptake, differentiation of pathologic uptake from physiologic uptake, and improvements in guiding and evaluating therapy (*13,14*). A study of 204 patients at Rambam Medical Center (*15*) with an integrated PET/CT system concluded that the diagnostic accuracy of PET was improved in approximately 50% of patients. PET/CT fusion images improved the characterization of equivocal lesions as definitely benign in 10% of sites and definitely malignant in 5% of sites. These images precisely defined the anatomic location of malignant ^{18}F-FDG uptake in 6% of patients and led to retrospective lesion detection on PET or CT in 8% of patients. The results of PET/CT had an impact on management in 14% of patients in comparison with PET alone. Antoch et al. (*16*) reviewed the accuracy of PET/CT for tumor staging in 260 patients with solid tumors. Tumor resection with T-stage verification was performed in 77 of 260 patients, operative assessment of N-stage tumors was performed in 72 of 260 patients, and pathologic M-stage tumors were verified in 57 of 260 patients. PET/CT was significantly more accurate for staging than were CT alone, PET alone, and side-by-side PET and CT. The stage was accurately determined by PET/CT in 84% of patients, by side-by-side PET and CT in 76% of patients, by CT alone in 63% of patients, and by PET alone in 64% of patients. Integrated PET/CT had an impact on the treatment plan in 6%, 15%, and 17% of patients compared with side-by side PET and CT, CT alone, and PET alone, respectively. The performance of PET/CT was evaluated in a group of 27 patients referred for restaging of lymphoma with 12 mo of follow-up as a standard of reference (*17*). Patient-based evaluation showed higher sensitivity for ^{18}F-FDG PET/CT (93%) and for side-by-side ^{18}F-FDG PET and CT (93%) than for ^{18}F-FDG PET alone (86%) or for CT alone (78%).

Head and Neck. Evaluation of the neck is extremely complex because of physiologic variations of uptake in muscular, lymphoid, glandular, and fatty tissue. The problem is compounded in postoperative patients because of the distorted anatomy. Therefore, interpretation of anatomic and molecular images in correlation with each other is critical. When the neck is the region of interest, the images should be acquired with the arms positioned at the side of

the body and the head and neck immobilized. Goerres et al. (*18*) described ^{18}F-FDG uptake in normal anatomy and in benign lesions and changes resulting from treatment.

Chest Tumors: Lung Cancer and Esophageal Cancer. PET/CT in the chest is limited by relatively inaccurate coregistration of PET and CT images because of the motion of the diaphragm. Integrated PET/CT images are particularly helpful for localizing ^{18}F-FDG–avid lymph nodes in the mediastinum and for evaluating chest wall invasion. CT images also should be examined carefully for the detection of lesions that may be malignant but that may not be ^{18}F-FDG avid, such as bronchoalveolar carcinoma. A prospective study of 50 patients with suspected or proven non–small cell lung cancer compared CT alone, PET alone, visually correlated PET and CT, and integrated PET/CT for staging (*19*). The standard of reference was histopathologic assessment of tumor stage and node stage. In this study, integrated PET/CT provided additional information in 41% of patients, and tumor staging was significantly more accurate with integrated PET/CT than with CT alone. The higher accuracy of ^{18}F-FDG PET/CT for TNM staging than of CT alone or of PET alone was documented in another study of 27 patients with non–small cell lung cancer and with histopathologic assessment as the standard of reference (*20*). PET/CT findings led to a treatment change for 19% of patients compared with CT alone and for 15% of patients compared with PET alone.

Most of the work regarding the role of PET and PET/CT in guiding radiation therapy has involved patients with non–small cell lung cancer and has been reviewed by Bradley et al. (*21*). The potential benefit of incorporating PET data into conventional radiation therapy treatment planning was documented in a study of 11 patients with non–small cell lung cancer (*6*). Patients were immobilized in the treatment position for the acquisition of both CT and ^{18}F-FDG PET images. For all patients, there was a change in the planned target volume outline on the basis of a comparison of CT images with PET/CT fusion images. In 7 of 11 patients, the planned target volume was increased by an average of 19% to incorporate nodal disease. In the other 4 patients, the planned target volume was decreased by an average of 18% to exclude atelectasis and to reduce radiation doses delivered to the nearby spinal cord or heart.

Abdominal and Pelvic Tumors. PET/CT fusion images may be especially important in the abdomen and pelvis. PET images alone may be difficult to interpret because of the absence of anatomic landmarks (other than the liver, kidneys, and bladder), the presence of nonspecific uptake in the stomach, small bowel, and colon, and the urinary excretion of ^{18}F-FDG. A study of 46 patients who had colorectal cancer and who were referred for ^{18}F-FDG PET with an integrated PET/CT system concluded that more definitely normal and definitely abnormal lesion characterizations were made with the PET/CT fusion images than with images from either modality alone, with fewer equivocal lesions. In addition, more lesions could be definitively localized (*22*).

Will PET/CT Become the Norm?

Because of the benefits of the combined technique described above, integrated PET/CT has become the modality of choice at many institutions at which this technology is available. The need for reviewing the CT scan in interpreting the PET scan has been demonstrated clearly, as has the added advantage of PET/CT image fusion over visually correlated PET and CT.

SPECIFICATIONS OF EXAMINATION

Issues Regarding Intravenous and Oral Contrast Materials

Intravenous contrast materials cause blood vessels and organs to enhance or increase in attenuation on CT images, with vascular enhancement being particularly vivid during the arterial phase. When arterial-phase CT images are used for attenuation correction, overcorrection may create artifacts of increased uptake on ^{18}F-FDG PET images (*23*). When artifacts are produced on attenuation-corrected images, viewing of non–attenuation-corrected images is important. When venous-phase CT images are used for attenuation correction, the effect on PET/CT is minimal (*24*). High-density oral contrast agents (*25*) and metallic implants (*26*) can create artifacts. However, the administration of dilute oral contrast agents or water results in minimal overcorrection and does not interfere with the accurate interpretation of ^{18}F-FDG PET images (*25,27*). As the algorithms for attenuation correction have become more sophisticated, artifacts from oral and intravenous contrast materials and metals have diminished.

The complex issue of the optimal CT protocol to use in combination with PET is still being debated. Optimal attenuation correction procedures for avoiding CT contrast agent artifacts and optimal procedures for avoiding artifacts resulting from potential mismatches in respiration and patient positioning between CT and PET examinations (*28,29*) have yet to be fully defined. Many institutions are now administering oral contrast agents and using portal venous–phase contrast-enhanced scanning to obtain both a diagnostic CT scan and an attenuation correction scan for PET when both diagnostic CT and ^{18}F-FDG PET have been ordered. However, CT during the portal venous phase alone is not optimal for detecting and characterizing some tumors in the abdomen and pelvis.

To obtain the most information from a PET/CT scan, a diagnostic CT scan usually should be performed with the PET scan. However, there are circumstances when a scan performed with a low current to minimize the radiation dose to the patient may be appropriate, such as when an optimized diagnostic CT scan has been performed recently and the CT scan would be used only for attenuation correction and anatomic correlation. In addition, data from the University of Zurich indicated that contrast enhancement is not

really needed when PET/CT is performed for the evaluation of patients with lymphoma (*30*).

When an optimized diagnostic CT scan is performed, the examination should be supervised and interpreted by a physician who meets the criteria in the ACR Practice Guideline for Performing and Interpreting Diagnostic Computed Tomography. The CT protocol is based on the clinical indication for the scan and the imaging studies previously performed. For example, for a head and neck cancer indication, an extracranial head and neck protocol should be used. For a lung nodule evaluation, a thoracic protocol should be used. Most PET studies include imaging from the external auditory meatus to the midthigh region. Thus, even when a CT protocol is tailored for a limited part of the body, the CT acquisition must cover the extent of the PET scan.

Because most ^{18}F-FDG PET scans are performed for the evaluation of metastatic disease, CT scans should include the extracranial neck, chest, abdomen, and pelvis. An intraluminal gastrointestinal contrast agent may be used to visualize the gastrointestinal tract unless it is contraindicated or not needed for the clinical situation. Dense iodine or barium oral contrast agents should be avoided so that artifacts will not occur when CT scans are used for attenuation correction or diagnosis. When needed, intravenous contrast material and an appropriate injection technique should be used. If intravenous contrast material is contraindicated, such as when a patient has renal insufficiency or a history of moderate or severe allergy to iodinated contrast agents, then a nonenhanced study may be performed.

The supervising physician should determine the technical factors and specific protocol to be used for the CT acquisition and processing.

When the CT scan is to be used only for attenuation correction with the PET scan, a low current (10 mA) may be used. For anatomic localization, a current of 80 mA provides adequate images. However, a higher current is required for most diagnostic applications.

Issues Regarding Patient Positioning and Acquisition Protocols

Whole-body PET/CT scans typically are acquired from the external auditory meatus to the midthigh region. Patients are scanned with their arms raised above their heads if that position can be tolerated. For patients who have head and neck cancer or suspected neck pathology as the indication for the examination, it is preferable to perform the study with the patient's arms at the side of the body to avoid artifacts in the region of greatest interest on the CT scan. When pathology exists in both the neck and the body, 2 separate scans can be considered: 1 over the neck and upper chest with arms along the side and the other over the lower chest, abdomen, and pelvis with arms elevated. For patients with melanoma or other malignancies that involve the extremities, it is recommended that both upper and lower extremities be included in the images. Images of the head

should be included for patients with known or suspected scalp involvement.

Issues Regarding Phase of Respiration During CT Acquisition

Because ^{18}F-FDG emission images must be acquired during normal breathing, there is still a debate as to whether optimal attenuation maps are provided by obtaining CT scans during a breath-holding technique or during normal breathing (*31,32*). Respiratory motion results in inaccurate localization of lesions at the base of the lungs or the dome of the liver in about 2% of patients (*33,34*).

Coaching patients to hold their breath at end-tidal volume during a CT examination can minimize artifacts from misregistration. Breath holding during maximum inspiration or maximum expiration is not recommended, because doing so will increase the degree of misregistration artifacts.

In the future, respiratory gating likely will become available. Respiratory gating may become especially important when a PET/CT study is used for the evaluation of small lung nodules and for radiation therapy planning.

Limited Versus Whole-Body Examinations

For some indications, limited regional PET/CT scans may be appropriate. Evaluation of a solitary pulmonary nodule is an example; however, if the nodule is malignant, then whole-body scanning is beneficial for initial staging. Another example is the diagnosis of head and neck cancer, for which including only the extracranial head, neck, and chest may be appropriate. For determining the effect of therapy in a patient with locally advanced breast cancer, regional imaging of the chest that includes the breasts may be appropriate.

Can CT from PET/CT Meet the Level of Quality of Diagnostic CT?

A CT scan obtained as part of PET/CT can meet the level of quality of imaging of a diagnostic CT scan. The factors affecting the quality of a CT examination include breath holding, the positioning of the patient's arms, the rate of injection and volume of intravenous contrast material, the timing of scanning relative to the timing of injection, the use of oral contrast material, collimation, slice thickness, pitch, gantry rotation time, and tube current and voltage. Performing an examination that allows attenuation correction for the PET scan yet provides adequate diagnostic quality requires some compromises. However, a range of CT techniques is considered diagnostically acceptable, and the compromises required are within this range.

CT scans usually are performed while patients hold their breath. For a PET/CT examination, because the patient is breathing during the several-minute acquisition of the PET scan and because the majority of the respiratory cycle is at or near end-tidal volume, the best registration of PET and CT scans occurs when the scans are obtained with the breath hold performed at end-tidal volume. Although diagnostic chest CT scans typically are acquired during the end of

inspiration, in most cases CT scans obtained at end-tidal volume can be diagnostic.

Placing the patient's arms at the side of the body rather than over the head can create streak artifacts through images of the chest and abdomen. However, placing the arms on a pillow, increasing the distance of the arms from the body, can minimize these artifacts. Another limitation of PET/CT involves the use of oral contrast material, which is routine for CT scans of the abdomen and pelvis. The density of conventional oral contrast material may affect the accuracy of attenuation correction. However, water or new low-attenuation oral contrast agents with limited absorption may replace high-density oral contrast agents.

As noted above, a CT scan with oral or intravenous contrast material can be used for attenuation correction. There may be limitations on the use of some phases of a contrast-enhanced CT scan because the anatomic extents of PET and CT scans must match. However, improvements in software could overcome some of the present limitations on the use of a CT scan for attenuation correction. If the needs of both the CT scan and the PET scan are considered, then thoughtful protocols can be designed to minimize compromises in diagnostic quality for either study or their coregistration.

Is Low-Dose CT Adequate?

A low-dose CT scan is adequate for attenuation correction and anatomic localization for a PET scan. It is not adequate for use as a diagnostic CT scan because of increased image noise.

Cardiac Gating

Cardiac gating is used for CT coronary artery calcium scoring, CT coronary angiography, and PET myocardial perfusion imaging. For radiation therapy planning, cardiac gating may be recommended in the future as well.

QUALIFICATIONS OF PERSONNEL

Physicians

As stated in the Prologue of this article, training requirements for those seeking to perform and interpret the results of PET/CT are controversial, and agreement between the ACR and the SNM has not been reached. The SNM considers the amount of on-the-job training in CT presented in this proposal to be adequate for radiologists without recent CT experience and nuclear medicine physicians to supervise and interpret a CT study performed concurrently with a PET study regardless of the protocol used. The ACR position is that the training outlined in this section may well be sufficient to allow adequate interpretation of the CT component of PET/CT for anatomic localization only, but it is not consistent with the existing ACR Practice Guideline for Performing and Interpreting Diagnostic Computed Tomography and as such does not prescribe sufficient training for the performance and interpretation of diagnostic CT. Thus, the ACR has not approved or endorsed the training require-

ments for diagnostic purposes. However, because PET/CT is a new and rapidly evolving technology, there may well be a need to consider new requirements for CT interpretation in the specific setting of hybrid technologies used by imaging specialists. Collaborative discussions continue.

The use of PET/CT technology is becoming common practice. Because it is inefficient for PET/CT images to be interpreted by 2 different imaging experts and then for their observations to be integrated, there is a need to define the training for persons who can interpret and integrate both components of PET/CT scans. Regardless of previous training, imaging experts interpreting PET/CT scans should have appropriate training in both PET and CT. Ideally, a diagnostic radiologist who has not received training in PET should have training experience in PET similar to that of a nuclear medicine physician, and a nuclear medicine physician ideally should have training experience in CT similar to that of a diagnostic radiologist. A diagnostic radiologist working in a practice that does not include a nuclear medicine physician with expertise in PET should obtain training in all aspects of PET so that he or she can both supervise and interpret PET scans. A nuclear medicine physician working in a practice that does not include a diagnostic radiologist with expertise in CT should obtain training in all aspects of CT so that he or she can supervise and interpret CT scans.

However, it is difficult to quantify training in CT in a diagnostic radiology residency or PET training in a nuclear medicine residency because training is pervasive and includes didactic lectures, interdisciplinary conferences, case interpretation, informal teaching, reading, consultations, and evening and weekend calls. In most instances, it is not feasible for a practicing diagnostic radiologist to duplicate exactly the PET training that a nuclear medicine physician receives during a nuclear medicine residency or for a practicing nuclear medicine physician to duplicate the CT training obtained in a diagnostic radiology residency. However, CT interpretations for all physicians should include a reasonable distribution of head and neck, chest, abdomen, and pelvis images.

Issues in Training Residents

Curriculum for Radiology Residents. Diagnostic radiology residents spend 4 y in a diagnostic radiology training program. As CT has become a ubiquitous diagnostic tool, most diagnostic radiology residency training programs include extensive training in CT (including neck, chest, abdomen, pelvis, and extremities), typically 30% of a resident's time. It is not unusual for a resident to participate in the supervision and interpretation of CT examinations of more than 30 patients per day, participating in and interpreting many thousands of CT studies during the residency period. The American Board of Radiology (ABR) requires specific training in nuclear medicine. Diagnostic radiology residents should participate in the evaluation and interpretation of at least 150 PET/CT scans under the supervision of qualified nuclear medicine physicians and diagnostic radiologists.

Curriculum for Nuclear Medicine Residents. Nuclear medicine residents spend 2 y in a nuclear medicine training program. For most programs, the resident spends at least 25% of the time on PET or PET/CT; in this setting, typically 7–10 PET/CT scans are performed per day. Training in correlative imaging such as CT is expected according to the guidelines of the Residency Review Committee for Nuclear Medicine. The American Board of Nuclear Medicine (ABNM) is in the process of changing its training requirements for its examinees from 2 to 3 y; part of the rationale for the third year is to inculcate an understanding and appreciation of the correlation of CT with nuclear medicine examinations, especially PET.

Issues in On-The-Job Training

Nuclear Medicine Physicians. Physicians who have been certified by the ABNM are referred to as nuclear medicine physicians.

Nuclear medicine physicians and other physicians having the qualifications listed in the ACR Technical Standard for Diagnostic Procedures Using Radiopharmaceuticals should have received training in the performance and interpretation of CT that includes 100 h of CME; directly supervised the interpretation of CT examinations of 500 patients, with a reasonable distribution of CT of the neck, chest, abdomen, and pelvis; received training in the physics of diagnostic radiology; completed 8 h of CME devoted to PET/CT; and supervised the interpretation of 150 PET/CT examinations (Table 1). Most CT examinations include multiple body areas (e.g., neck, chest, abdomen, and pelvis). When CT images of the neck, chest, abdomen, and pelvis are obtained during 1 scanning session, for the purposes of training, this session is considered to be a single examination rather than 4 examinations.

Radiologists Who Are Experienced in CT. When formal training has occurred during a residency in diagnostic radiology and the physician is certified by the ABR or has interpreted and reported 300 CT examinations in the past 36 mo, this individual is referred to as a diagnostic radiologist. Diagnostic radiologists having a certificate of added qualifications in nuclear radiology are referred to as nuclear radiologists. A physician who completes training in diagnostic radiology and completes 1 y of training in an Accreditation Council for Graduate Medical Education–approved nuclear medicine training program is permitted to take the examination given by the ABNM.

A diagnostic radiologist who interprets CT scans should demonstrate evidence of continuing competence in the interpretation and reporting of those examinations (see the ACR Practice Guideline for Performing and Interpreting Diagnostic Computed Tomography). If competence is assured primarily on the basis of continuing experience, then a minimum of 100 CT examinations per year are recommended to maintain the physician's skills.

Nuclear radiologists and radiologists who have recent experience in body CT and who are certified by the ABNM should participate in PET/CT training similar to that required for nuclear medicine physicians: They should have 8 h of CME devoted to PET/CT, and they should have directly supervised the interpretation of 150 PET/CT examinations (Table 1).

Diagnostic radiologists and other physicians who meet the qualifications listed in the ACR Practice Guideline for Performing and Interpreting Diagnostic Computed Tomography and who have recent experience in body CT should participate in the supervised interpretation of 150 PET/CT examinations and should have 35 h of CME devoted to PET or PET/CT (Table 1).

TABLE 1
Summary of PET/CT On-The-Job Training

Training	ABMS certification	PET/CT interpretations (supervised)	CT interpretations (supervised)*	PET/CT CME (h)	CT CME (h)
Nuclear medicine	ABNM	150	500	8	100
Diagnostic radiology (recent CT)[†]	ABR	150		35	
Nuclear radiology (recent CT)[†]	ABR	150		8	
Radiology (recent CT)[†]	ABR and ABNM	150		8	
Diagnostic radiology (no recent CT)	ABR	150	500	35	100
Other[‡]	Neither ABR nor ABNM	150	Per ACR guidelines for CT	35	Per ACR guidelines for CT

*CT examinations should include reasonable distribution of head and neck, chest, abdomen, and pelvis images.
[†]Recent experience in body CT (100 body CT examinations per year for past 5 y).
[‡]Other physicians who comply with ACR guidelines for interpretation of CT and interpretation of nuclear medicine studies.
ABMS = American Board of Medical Specialties.
ACR considers this training the minimum for supervising and interpreting anatomic localization in PET/CT setting, but it is not consistent with existing ACR Practice Guideline for Performing and Interpreting Diagnostic Computed Tomography.
SNM considers this training sufficient for supervising and interpreting CT studies performed with PET studies regardless of protocol used.

Radiologists with No Recent CT Experience. Radiologists with no recent CT experience should have received training in the performance and interpretation of CT that includes 100 h of CME; directly supervised the interpretation of 500 CT regional examinations, with a reasonable distribution of CT of the neck, chest, abdomen, and pelvis; received training in the CT physics of diagnostic radiology; supervised the interpretation of 150 PET/CT examinations; and completed 35 h of CME devoted to PET or PET/CT (Table 1).

Other Physicians. Other physicians who are not certified by ABR or ABNM should comply with existing ACR guidelines for the interpretation of CT and for the interpretation of nuclear medicine studies, have supervised the interpretation of 150 PET/CT examinations, and have completed 35 h of CME devoted to PET or PET/CT (Table 1).

Measurement of Training, Experience, and Competence. Measurement of training, experience, and competence is a complex issue, and there are no well-accepted parameters available for evaluation. The number of studies interpreted most often is used as a measurement of training and experience. The measurement of competence is more controversial because it involves the complexity of how an individual integrates the knowledge acquired to apply it to clinical practice.

The number of studies necessary to be interpreted before competency is attained is also controversial and related to the complexity of the imaging study. However, a reasonable number of studies required can be determined on the basis of existing guidelines. For example, the training and experience needed for a nonradiologist to interpret specific radiologic studies according to existing ACR guidelines are 200 h of CME credit and 500 studies interpreted under supervision in the specific field of radiology. Because nuclear medicine residency training programs are required to include correlative imaging in their curricula and rotations (assuming that this training is supervised by someone with expertise in correlative imaging), it may be reasonable to decrease the additional training for nuclear medicine physicians to 100 h of CME credit in CT but keep the experience to the interpretation of 500 CT examinations under supervision. Similarly, radiology residency training programs are required to include a specific number of months of rotations in nuclear medicine, some of which may be devoted to PET. However, the more widespread use and availability of clinical PET did not occur until clinical indications became approved for reimbursement in 1998. Therefore, the requirements of 35 h of CME credit in PET/CT and 150 PET/CT studies interpreted under supervision seem reasonable for diagnostic radiologists.

A preceptorship statement documenting the number of cases interpreted under supervision is necessary to document evidence of training and experience.

Interpretation under supervision by an experienced imager in the field has been the most common pathway to gaining training and experience. An experienced imager in the field is defined as one who meets ACR guidelines for the interpretation of a particular set of studies, including the maintenance of competence.

If experience in interpreting studies is gained alternatively, then documentation of the source of as well as the numbers and types of cases is necessary.

In the future, both ABR and ABNM certifying and recertifying examinations will include testing on CT, PET, and PET/CT. The ABNM is currently considering the possibility of using recertification through examination as evidence of PET/CT training.

Separate curricula for PET and CT are given in Appendices B and C. It is likely that in the future, integrated curricula including PET and CT will be developed.

CME credits can be obtained by attending scientific meetings, symposia, conferences, or courses. Alternatively, CME accredited courses and lectures are available on CD-ROM and at various Web sites. It is the responsibility of the training physician to provide evidence and documentation of CME credit in specific areas of CT or PET. CME credit for PET/CT activities should be allocated to PET training unless diagnostic CT was performed concurrently.

All physicians interpreting PET/CT scans should meet the guidelines described above. No grandfathering is to be granted. However, some physicians may already meet these guidelines if they are qualified to supervise the interpretation of both CT and PET/CT as defined above.

Physician Coverage Models and Scenarios

Monitoring and Supervising. Monitoring and supervising of PET/CT studies should be performed by physicians trained in accordance with ACR PET or CT guidelines.

Interpretation of Results. A PET/CT report should specify the CT protocol used and whether the CT scan was done for anatomic localization only or for diagnostic purposes with the appropriate CT protocol for the clinical scenario and body region of interest. If the CT scan was done for anatomic localization only, then the integrated PET/CT report should include the incidental findings on the CT scan that are relevant to patient care. If the CT scan was a diagnostic examination, then the PET/CT report should refer to the diagnostic CT scan report for findings not related to the PET/CT findings.

Evolution of Scenarios. On the basis of common practice in the United States, most PET/CT scans will be interpreted by diagnostic radiologists with additional training in PET and PET/CT. In some centers, nuclear medicine physicians with additional training in CT will interpret PET/CT scans. In other centers, PET scans will be interpreted by nuclear medicine physicians with expertise in PET, and CT scans will be interpreted by diagnostic radiologists with expertise in CT. A conjoint summary should be issued to avoid discrepancies between the reports. All of these practice models are considered acceptable as long as the interpreting physicians have the requisite training and experience.

Degree of Correlation Required Between PET/CT and Prior CT Examinations. Integrated PET/CT studies should be correlated with previous diagnostic CT, previous PET,

previous PET/CT, and all appropriate imaging studies and clinical data that are relevant.

Technologists

PET/CT technology presents issues for training, experience, competence, and certification of technologists operating these systems similar to those that it presents for physicians. The issues regarding technologists are addressed by the American Registry of Radiologic Technologists and the Nuclear Medicine Technology Certification Board. Representatives of the technologist section of the SNM and the American Society of Radiologic Technologists met in 2002 to discuss the training of technologists for PET/CT. The recommendations from that consensus conference and the plans for training technologists in PET/CT were reported in 2002 (35).

Medical Physicists

PET/CT technology is in evolution. Medical physicists need to keep pace with the state-of-the-art equipment and with advances in technology, including the potential development of other hybrid techniques. Qualified medical physicists need to be competent in the subfields of both CT and PET. A qualified medical physicist is an individual who is competent to practice independently 1 or more of the subfields in medical physics. The ACR recommends continuing education in the appropriate subfield and certification by the ABR to demonstrate that an individual is competent to practice in that subfield of medical physics as a qualified medical physicist.

PRACTICE GUIDELINES

PET/CT technology is becoming rapidly available throughout the United States and includes both fixed sites and mobile PET/CT units. Health care providers are under pressure to make this new technology available to their patients. Local radiologists and nuclear medicine physicians are under pressure to supervise, monitor, and interpret these combined studies, most of the time with limited experience in CT, PET, or both. It is important to make practice guidelines available as soon as feasible even as the technology is progressing. These practice guidelines may need more frequent updates and revisions than the usual 5 y recommended by the ACR, as permitted by ACR bylaws. It is also extremely important for these practice guidelines to be the result of a joint effort by radiologists and nuclear medicine physicians.

SAFETY ISSUES

Personnel

Training in PET/CT should address the special considerations of radiation exposure of personnel handling positron-emitting isotopes. Benatar et al. (36) investigated the whole-body doses received by staff in a dedicated clinical PET center and then developed projected dose estimates for staff in departments not originally designed for positron imaging. The average whole-body dose for a PET technologist was approximately 5.5 μSv per patient study. Because of the short half-life

of ^{18}F (110 min), radiation exposure of the general public after patients leave a PET facility is considered negligible (37).

Patients

Radiation doses to patients need to be kept as low as reasonably achievable, especially for pediatric patients. With a low-dose transmission CT scan, the radiation dose to the patient typically can be decreased to approximately half that of a diagnostic CT scan. Because the CT scan is used for attenuation correction, breasts and genitals cannot be shielded. Radiation doses must be taken into consideration when a diagnostic CT scan is requested, and the guidelines for pediatric CT scans should be followed.

REGULATORY AND LEGAL ISSUES

Does CT Need to Be Interpreted Even When Used Only for Localization or Attenuation Correction?

The PET/CT report should specify whether the CT scan was done for anatomic localization only or for diagnostic purposes with the appropriate CT protocol for the clinical indication and the body region of interest. If the CT scan was done for anatomic localization only, then the integrated PET/CT report should include the incidental findings on the CT scan that are relevant to patient care.

Is a Disclaimer Sufficient When CT Is Not Interpreted?

A disclaimer that the CT scan is nondiagnostic may be appropriate if the CT scan was performed for attenuation correction with a very low current, such as 10 mA. However, the interpreting physician still has a duty to report any findings that are relevant to patient care.

Self-Referral and Stark Law

In the regulations issued pursuant to the Stark law, the Centers for Medicare and Medicaid Services address physician referrals to entities with which they have a financial relationship. These regulations protect beneficiaries and taxpayers from abusive referral patterns while providing straightforward rules for physicians and providers to comply with the law. These regulations apply to diagnostic radiology procedures; nuclear medicine procedures were exempted from the original regulations, and that exemption was reaffirmed in the interim final regulations published in early 2004. With PET/CT technology, the issue arises as to whether PET/CT should be considered a diagnostic radiology procedure or a nuclear medicine procedure. Currently, this question is unresolved.

REIMBURSEMENT AND ECONOMIC ISSUES

Prior CT Scan

The clinically indicated frequency of CT in patient management depends on the diagnosis and indications for the scan. Some third-party payers have set limits on the frequency for coverage.

Prior PET Scan

The clinically indicated frequency of PET in patient management depends on the diagnosis and indications for

the scan. Some third-party payers have limited the frequency to every 3 mo. For therapeutic monitoring, which is becoming an important indication for PET, a 3-mo interval between PET scans may be too long.

New Current Procedural Terminology (CPT) Codes

Recently, new CPT codes were created by the American Medical Association CPT Panel that include codes for PET and PET/CT. The Centers for Medicare and Medicaid Services began using these codes effective January 30, 2005. The new codes are resulting in some confusion concerning billing for both a PET/CT and CT scan when both diagnostic studies are ordered and the scans are performed on the same scanner. Clarification of the correct method for billing these procedures is expected to be forthcoming from CMS.

CONCLUSION

The diagnostic advantages of integrated PET/CT include improved detection and characterization of lesions on both CT and PET images, better differentiation of physiologic foci from pathologic foci of metabolism, and better localization of pathologic foci. This new technology provides more accurate interpretations of both CT and PET images and results in better patient care. PET/CT fusion images affect clinical management by guiding further procedures (e.g., biopsy, surgery, and radiation therapy), excluding the need for additional procedures, and changing both inter- and intramodality therapies.

The combined approach of CT attenuation correction and image fusion with PET is a new diagnostic tool for nuclear medicine imaging, radiation therapy, and surgical planning. The applications that have emerged for this technology with ^{18}F-FDG as the radiotracer will expand even further with the array of new promising PET tracers.

The combination of PET and CT challenges health care providers, radiologists, and nuclear medicine physicians to make this technology available for patient care on a timely basis. Although there are rapid new technologic developments in the field, there is a need for practice guidelines to achieve and maintain a high standard of care. Practice guidelines should be the result of collaboration between radiologists and nuclear medicine physicians and should be revised as appropriate as the technology and experience with PET/CT evolve.

APPENDIX A

Joint Working Group

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APPENDIX B

Curriculum Topics for Cross-Training in PET/CT Interpretation: Principles of PET and PET/CT

I. Basics: physics, chemistry, and camera techniques
  A. Historical development of PET
  > Physics background
  > Positron tomographs and detectors for PET
  > Quality control
  > PET/CT
  B. Image reconstruction, quantification, and SUV
  > Reconstruction of radioactivity distribution
  > Factors that influence quantitative accuracy
  >> Coincidence events and acquisition modes
  >> Dead-time correction
  >> Correction for random coincidences
  >> Correction for scattered coincidences
  >> Attenuation correction
  >> Choice of filter for filtered backprojection reconstruction
  > Quantitative analysis of ^{18}F-FDG PET: tracer kinetic modeling
  > SUV
  C. Partial-volume effects and corrections for brain and whole body
  D. Radiation safety in PET
  > Radiation protection of patients
  > Radiation protection of personnel
  > Environmental protection
  E. Biochemical concept and radiochemical synthesis of ^{18}F-FDG
  > Biochemistry of glucose and 2-deoxyglucose
  > Radiochemistry of ^{18}F-FDG
  > Validated methods for synthesizing ^{18}F-FDG
  > ^{18}F-FDG quality control
  F. Current development of ^{18}F-labeled PET tracers
  > Analogs of ^{18}F-FDG
  > Amino acids
  > DNA building blocks
  > Peptides and steroids
  > Bones

G. PET and PET/CT
  PET imaging protocols
  Challenges of retrospective image alignment
  PET/CT protocols
    Acquisition protocols
    Effects of contrast enhancement
    CT-based quantitative corrections
    Image reconstruction and dual-modality
      image display
H. Physiologic distribution of ^{18}F-FDG, normal variants, and artifacts

II. Oncologic applications
  Each type of tumor includes the following topics:
    Incidence, etiology, and epidemiology
    Histopathologic classification
    Conventional diagnostic and therapeutic methods
    Roles of ^{18}F-FDG PET and PET/CT
    Technical considerations
    Diagnosis of primary tumors
    Grading
    Initial staging
    Monitoring of therapy
    Diagnosis of recurrence and restaging
    Prognosis
    Impact on management
  Other PET radiopharmaceuticals
  A. Brain tumors
  B. Head and neck tumors
  C. Carcinoma of unknown primary source
  D. Thyroid carcinomas
  E. Lung cancer
  F. Pancreatic cancer
  G. Hepatobiliary tumors
  H. Colorectal carcinomas
  L. Hodgkin's and non-Hodgkin's lymphomas
  J. Testicular cancer
  K. Prostatic cancer
  L. Malignant melanomas
  M. Musculoskeletal tumors and soft-tissue sarcomas
  N. Metastatic bone disease
  O. Renal cell and uroepithelial cancer
  P. Endocrine and neuroendocrine tumors
  Q. Breast cancer
  R. Esophageal and gastric cancer
  S. Ovarian and cervical cancer
  T. Pitfalls in interpretation of PET studies
  U. PET in pediatrics
  V. PET and PET/CT in radiation therapy
  W. Monitoring of treatment response with PET and PET/CT
  X. Cost-effectiveness of PET and PET/CT in patient management
  Y. Cancer screening with PET and PET/CT
  Z. PET and PET/CT reimbursement

III. Infectious diseases
  A. Patient preparation and protocols
  B. PET imaging in HIV patients
  C. PET imaging in patients with suspected prosthetic infections
  D. PET imaging in patients with fever of unknown origin

APPENDIX C

Curriculum Topics for Cross-Training in PET/CT Interpretation: Principles of Anatomy and Pathology in Body CT

  I. Physics and instrumentation
  II. Neck
    A. Anatomy
      1. Neck "spaces" and compartments
      2. Normal laryngeal and pharyngeal structures
      3. Normal size and distribution of lymph nodes
    B. Pathology
      1. Extranodal masses
        a) Congenital and developmental (e.g., branchial cleft cyst)
        b) Inflammatory and infectious (e.g., abscess)
        c) Neoplastic
          i) Laryngeal carcinoma (staging)
          ii) Pharyngeal carcinoma (staging)
      2. Nodal masses
        a) Benign (reactive hyperplasia)
        b) Malignant
  III. Thorax
    A. Anatomy
      1. Lungs: lobar anatomy and fissures
      2. Normal size and distribution of lymph nodes: American Thoracic Society classification of regional nodal stations
      3. Pericardial recesses
      4. Mediastinum (e.g., vessels and esophagus)
      5. Pleura
      6. Diaphragm
    B. Pathology
      1. Lung masses and nodules
        a) Benign (e.g., granulomas, rounded atelectasis, and hamartomas)
        b) Malignant
          i) Lung cancer (different types and staging schemes)
          ii) Lung metastases
      2. Nodal masses
        a) Benign (e.g., granulomas, mononucleosis, and sarcoidosis)
        b) Malignant
          i) Lymphoma
          ii) Metastases
      3. Mediastinal masses
        a) Benign (e.g., thymic, cystic, neurogenic, and esophageal)

b) Malignant (e.g., esophageal cancer)
c) Infectious and inflammatory (e.g., after radiation or surgery)
4. Pleural masses
a) Benign: asbestos plaques, hemothorax, or empyema
b) Malignant
i) Mesothelioma
ii) Metastases
5. Diaphragm
a) Diaphragmatic variations and hernias
b) Retrocrural nodes and masses
IV. Abdomen
A. Anatomy
1. Abdominal wall: major muscles
2. Peritoneal and retroperitoneal spaces
a) Morison's pouch and paracolic gutters
b) Anterior pararenal, perirenal, and posterior pararenal
3. Abdominal viscera (normal anatomy and common variations)
4. Lymph node size and distribution
5. Great vessels: common congenital anomalies (e.g., duplication of inferior vena cava)
B. Pathology
1. Abdominal wall and peritoneal cavity
a) Benign (e.g., common hernias and ostomy sites)
b) Malignant (e.g., subcutaneous and muscle metastases)
2. Peritoneal and extraperitoneal
a) Benign: abscesses, fluid collections, and postoperative changes
b) Malignant
i) Peritoneal metastases
ii) Retroperitoneal sarcoma
3. Abdominal viscera
a) Bowel
i) Benign (e.g., inflammatory bowel disease, diverticulitis, and pseudomembranous colitis
ii) Malignant (primary and metastatic)
b) Liver
i) Benign masses: hemangiomas, cysts, focal nodular hyperplasia, focal fat, and abscesses
ii) Malignant masses: metastases, hepatocellular carcinoma, and cholangiocarcinoma
c) Biliary system
i) Benign: cholecystitis and cholangitis
ii) Malignant: gallbladder carcinoma and cholangiocarcinoma

d) Spleen
i) Benign: cysts, infarction, and accessory spleen
ii) Malignant: lymphoma and metastases
e) Pancreas
i) Benign: chronic pancreatitis and islet cell and serous cystic tumors
ii) Malignant
(a) Ductal, islet cell, and mucinous carcinomas
(b) Metastases
f) Kidneys
i) Benign
(a) Congenital anomalies, hydronephrosis, and scarring
(b) Cysts and angiomyolipoma
ii) Malignant
(a) Renal cell carcinoma (staging)
(b) Transitional cell carcinoma
g) Adrenal glands
i) Benign
(a) Pseudotumors
(b) Adenoma
(c) Pheochromocytoma
(d) Myelolipoma
ii) Malignant
(a) Metastases
(b) Carcinoma
4. Lymph nodes
a) Lymphadenopathy
i) Benign: inflammatory (e.g., mononucleosis and sarcoidosis)
ii) Malignant
(a) Lymphoma (differences in nodal involvement in Hodgkin's and non-Hodgkin's lymphomas)
(b) Metastases
V. Pelvis
A. Anatomy
1. Peritoneal and extraperitoneal spaces
2. Pelvic viscera
a) Prostate and seminal vesicles
b) Uterus, cervix, and ovaries
B. Pathology
1. Benign masses
a) Benign prostatic hypertrophy
b) Fibroids and adnexal cysts
c) Bladder diverticula and wall hypertrophy
2. Malignant
a) Prostatic cancer (staging)
b) Uterine and cervical cancer (staging)
c) Ovarian cancer (staging)
d) Bladder cancer (staging)

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