

PET/CT: a new imaging technology in nuclear medicine

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Abstract. This review discusses the technical background of combined PET and CT and considers the clinical applications of PET/CT imaging. Questions addressed include: Is PET/CT superior to PET imaging alone? If so, in which patient populations and in what respect? Can PET/CT imaging affect patient management? Can PET/CT be practiced economically? While much work remains to be done, the available data clearly suggest that PET/CT decreases imaging time per patient and, even for the experienced reader, significantly reduces the number of equivocal PET interpretations. PET/CT also has the ability to improve accuracy of PET image interpretation and to affect clinical decision making, thereby improving patient management. The nuclear medicine community should approach this new technology with an open mind and focus on its clinical usefulness. The decision regarding whether PET/CT should be part of the equipment in a given nuclear medicine or radiology practice largely depends on the specific patient population. It is concluded that present skepticism concerning combined PET/CT will subside once critics of this new modality have had the opportunity to clearly see on images its many advantages compared with either PET alone or conventional image fusion approaches.

Keywords: PET/CT imaging – Technical aspects – Acquisition protocols – Artifacts – Clinical applications

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Introduction

PET/CT merges two fundamentally different imaging technologies into one new device. Positron emission to-

mography (PET) is the four-dimensional (spatial distribution and time) distribution of a given radiotracer within the human body. It has been defined as an “imaging technology that measures and quantifies biochemical processes” [1]. Depending on the radiotracer, PET can assess regional and absolute blood flow, metabolism, protein synthesis, gene expression, tissue hypoxia, and the presence of abnormal proteins such as neurofibrillar plaques and tangles, and can also quantify receptors and cell membrane-bound transporter proteins (such as the sodium-iodine symporter). It is, therefore, often referred to as a “functional imaging” modality. Computed tomography (CT), on the other hand, primarily provides information about anatomy, and, when intravascular contrast is employed, blood flow and tissue permeability. The introduction of spiral and multidetector CT (MDCT) has enabled the implementation of a number of new and exciting clinical applications for CT (for instance, virtual colonoscopy and bronchoscopy, imaging of cardiac function, visualization of coronary arteries, and quantification of coronary calcification and, recently, also noncalcified plaques). Nevertheless, the information obtained essentially reflects anatomy and to some degree perfusion.

For practical purposes we define PET/CT as an imaging technology that combines high-quality PET and CT in a single device and provides simultaneous structural and metabolic (biochemical) information under (almost) identical conditions. The CT data are used for two purposes: (1) to calculate the attenuation correction for the PET scan, and (2) to provide anatomic information for comparison with the PET scan. This article will review the technical background of combined PET and CT and will then proceed to discuss the clinical applications of PET/CT imaging.

Some of the questions we will try to answer are: Is PET/CT superior to PET imaging alone? If so, in which patient populations and in what respect? Can PET/CT imaging affect patient management? Can PET/CT be practiced economically?

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Technical aspects of PET/CT imaging

Currently three vendors offer combined PET/CT machines. The “Biograph” and “Reveal” are manufactured by CPS Innovations (Knoxville, TN) and marketed by Siemens (Biograph) and CTI (Reveal). These units are BGO- and LSO-based (3D only) PET tomographs, combined with the Siemens “Somatom Emotion” CT system. “Discovery LS” and “Discovery ST” are manufactured by GE Medical Systems (Waukesha, WI). These units are BGO-based 2D/3D systems combined with a “Light-Speed” CT. “Gemini” is the PET/CT manufactured by Phillips (Bothell, WA). This unit combines a 3D GSO-based PET with the Philips MX8000D multislice CT scanner and provides an open system design in which PET and CT units can be physically separated and used individually. In this section, we shall focus on features common to all PET/CT systems.

CT systems

In all original CT scanners (1974–1987), the X-ray power was transferred to the X-ray tube using high-voltage cables wrapped around an elaborate set of rotating drums and pulleys. The rotating frame (or gantry) would spin 360° in one direction and create an image (or a slice), and then spin 360° back in the other direction to create a second slice. In between each slice, the gantry would come to a complete stop and then reverse directions while the patient table would be moved forward by an increment equal to the slice thickness. In the mid 1980s, the power slip ring was invented. The slip ring allows electric power to be transferred from a stationary power source onto the continuously rotating gantry. State of the art CT scanners with slip rings can now rotate continuously and do not have to slow down to start and stop. This innovation created a renaissance in CT technology through the introduction of multislice (spiral) CT. These spiral CT scanners can now image entire anatomic regions such as the lungs in a single breath-hold. Instead of acquiring a stack of individual slices, which may be misaligned due to slight patient motion or breathing (and lung/abdomen motion) between each slice, spiral CT acquires a volume of data. From this volume data set, a number of different images can be reconstructed, including “standard” transaxial CT slices, shaded surface images, volume-rendered images, or maximum intensity projection (MIP) images. The latter two options essentially resemble the classic display of PET emission images. In particular, the volume display permits the three-dimensional display of complex anatomic structures.

Recently, 16-slice CT systems were introduced. Two manufacturers, Siemens and GE, offer PET/CT scanners which employ 16-slice CT with their PET scanners (Biograph Sensation 16 and the Discovery LS 16 respectively).

The 16-slice CT systems can image an 80-cm torso in less than 20 s (420 ms/rotation, 1.5 mm collimation).

PET systems

PET tomographs are typically operated in one of four imaging protocols: (a) whole body, (b) single-field high-count density, (c) dynamic, and (d) gated.

In *whole body mode*, the physician determines the region of the body to be imaged. This can be limited to certain regions of the body (head and neck, thorax, abdomen) but in most cases includes the entire torso from the skull base to the inguinal regions (in patients with melanoma and neuroblastoma, the lower extremities are usually included since these diseases can occur at any site). After acquiring the spiral CT, where the patient table moves continuously through the imaging gantry, the emission PET images are acquired in the step and shoot mode, where the table remains in one position for several minutes to obtain sufficient counts for a diagnostic quality image before moving to the next bed position. The typical axial field of view (FOV) is 15 cm, which means that approximately 12 bed positions are required to image the average adult patient from the top of the head to the soles of the feet. Since most clinically significant diseases involve the torso, most institutions record PET images from the base of the skull to the upper thighs. The time of image acquisition per FOV varies from institution to institution, and among other factors depends upon the amount of activity injected, patient size, interval between tracer administration and image acquisition, detector material, and the acquisition mode (2D versus 3D; see below). The acquisition time can be as short as 1 min per FOV with the latest LSO-based PET/CT (Reveal RT; CTI, Knoxville, TN), although most images are recorded with 3–6 min per bed position.

For *high-count density studies*, images from a single FOV are acquired for 20–60 min. This mode of acquisition is primarily used in imaging the brain or heart.

A *dynamic image acquisition* is also performed for a single FOV; however, the full duration of the scan is divided into numerous successive time frames (or bins) so that tracer kinetics can be observed. Data derived from the sequence of images are frequently used in compartment models or to generate parametric images that reflect the time course of regional blood flow or metabolism (for instance in brain or myocardium) [2, 3, 4]. Dynamic imaging is also useful when performing (radio-) pharmacokinetic studies or establishing the optimal imaging time for a new radiopharmaceutical.

In *gated image acquisition*, images can be recorded in synchrony with a physiologic function, such as the respiratory or cardiac cycle. Respiratory gated images are particularly useful to characterize smaller lung or liver lesions, permit precise quantification of tracer uptake in these lesions, and guide radiation treatment planning;

Table 1. Physical and optical properties of scintillator crystals used in current PET/CT systems

Scintillator	BGO	LSO	GSO	NaI(Tl)
Density (g/cm ³)	7.13	7.40	6.71	3.67
Effective atomic number	74	66	59	51
Decay time (ns)	300	40	60	230
Index of refraction	2.15	1.82	1.85	1.85
Emission wave length (nm)	480	420	430	410
Relative light output	15	75	30	100
Rugged	Yes	Yes	No	No

cardiac gating permits quantitation of global and regional ventricular function [5, 6].

Detectors/crystals

The ideal PET detector should have a high stopping power for the 511-keV annihilation photons, produce a short and very intense light flash (photofluorescence), and provide accurate energy measurement and a short dead time. The types of crystals most commonly used in PET detectors include bismuth germanate oxide (BGO), cerium-doped lutetium oxyorthosilicate (LSO), cerium-doped gadolinium oxyorthosilicate (GSO), and thallium-doped sodium iodide (NaI). The physical properties of the crystal will ultimately affect the performance of the PET camera [7] (Table 1).

Image acquisition: 2D vs 3D technique

PET images can be acquired in either 2D or 3D mode (for details, see [8]). With 2D acquisitions, lead or tungsten septa are placed between the detectors to absorb scattered photons (out of slice activity). The septa reduce the amount of scatter to 10–15% of the total counts acquired and improve image contrast. Nevertheless, some scattered events will be recorded and, together with random coincidence events, degrade the image. A random event occurs when photons from two separate annihilation events are detected within the preset coincidence time window and are (erroneously) recorded as one coincidence event. The number of random events generally increases with the administered activity, and, for a given total count rate, is higher for 3D acquisitions.

In 3D acquisition, the septa are removed so that each individual detector is sensitive to radiation from a much larger area and the count rate increases by a factor of 5–6 [9]. The increased count rate of 3D imaging can be used to reduce the amount of tracer activity needed for the examination or to shorten the acquisition time [10]. Three-dimensional image acquisition is often used for brain PET or pediatric patients. There are some disadvantages to 3D imaging: First, there is an increased number of random events. For a given increment in activity in the FOV, the random count rate increases more rapidly than

does the true count rate. True coincident events increase linearly with radioactivity in the FOV, while the random rate scales as the square of the radioactivity in and near the FOV. Second, the count rate limit of the PET tomograph can be overwhelmed if there is too much activity in the FOV. With high count rates, pulses can “pile-up” and the detector may become paralyzed. Third, 3D data contain an increased scatter fraction. Scatter occurs when one (or both) annihilation photons are deflected within the body prior to detection; this results in an incorrect localization of the event and degrades the image. In 3D mode, the number of scattered events approaches half of all recorded events. Because of this, for proper quantification, a scatter correction must be applied to 3D data. Finally, 3D image acquisition also requires more computer memory and more time for image reconstruction.

In 2D image acquisition mode, the patient table is moved by a distance that guarantees overlap between the first slice of the new table position and the last slice of the previous table position. In 3D acquisition mode, there is more overlap between two adjacent table positions (i.e., the table is moved less than 15 cm from acquisition to acquisition), usually between 15% and 30% of the length of the FOV. This overlap is necessary to compensate for variations in the count sensitivity of the PET tomograph (the outer detector rings receive fewer coincidence events than detector rings in the center). Some PET/CT systems operate in 3D mode only (Biograph, Reveal, Gemini) while others can be used in either 2D or 3D mode (Discovery), according to institutional preferences.

Attenuation correction and quantitative analysis in PET vs PET/CT

PET images are initially reconstructed from emission data that are not corrected for attenuation of the 511-keV annihilation photons within the patient. These uncorrected images exhibit a characteristic outer rim of apparently increased activity along the periphery of the body and relatively lower tracer uptake in organs in the center of the body. A transmission scan is used to create an attenuation map. The patient-specific attenuation map is used to correct for this bias in the emission data (Fig. 1). Attenuation correction is also needed for semiquantitative

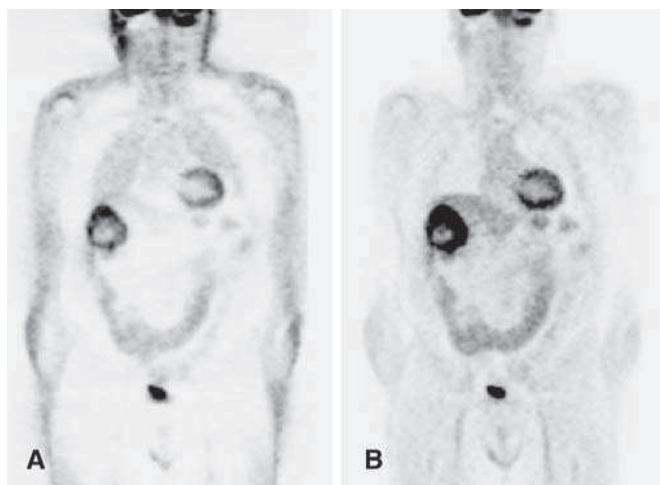


Fig. 1A, B. Non-attenuation-corrected images (A) and attenuation-corrected images (B) in a patient with liver metastasis

analysis of regional radiotracer uptake in tissue (SUV). In conventional PET imaging, the attenuation map is based on data from a transmission scan that is acquired with an external 511-keV germanium rod source. In PET/CT the transmission data for attenuation correction are derived from the CT scan. Hence, the CT images of the combined PET/CT serve the dual purpose of providing both structural information and the attenuation map for PET image attenuation correction.

However, since the CT images are acquired with a lower photon energy (110–140 kVp X-rays), CT attenuation coefficients need to be scaled to reflect the attenuation of 511-keV photons. This conversion needs to be accurate over a wide range of tissue densities in order to guarantee reproducibility and reciprocity of quantitative analysis with PET/CT. Phantom experiments and studies in patients have shown that this can be done relatively easily [11]. CT-corrected images tend to overestimate activity concentrations in tissue, and the magnitude of overestimation is greater for tissues with higher Hounsfield units (bone, concentrated i.v. or gastrointestinal contrast) [12]. One reason for these differences in measurements is the fact that attenuation of the 511-keV annihilation photons occurs primarily by Compton scatter, whereas attenuation of the lower energy CT X-ray photons occurs primarily due to photoelectric effects. The likelihood of the latter increases exponentially with the effective atomic number raised to the fourth power and is higher for calcium (bone), barium, and iodine (contrast agents) as compared with water or soft tissue. In contrast, the likelihood of Compton scatter is related linearly to electron density. For practical purposes it can be concluded that CT-based measurements of activity concentrations will be slightly higher than those from germanium-based images. Another reason for the differences between CT-based and transmission-based attenuation-corrected activity values is that external germani-

um-68 sources use monoenergetic 511-keV annihilation photons, whereas CT photons demonstrate a broad lower energy spectrum than their peak kVp settings. While significant differences between measurements in the same tissue can be demonstrated [12], the clinical relevance is likely small (in clinical studies it is irrelevant whether the SUV for a given lesion is 20 or 22). In addition, measurements of activity concentrations with germanium-based PET images also depend on a number of factors, including image reconstruction filters [13,14]. It is therefore generally recommended to perform follow-up studies with the same equipment and under the same conditions as baseline studies.

Clinical aspects of PET/CT imaging

Clinical applications

PET/CT was originally developed as a research device by investigators at the University of Pittsburgh. The prototype instrument was applied to study selected patients with cancer [15, 16]. In view of the striking enhancement in information available from PET/CT, commercial manufacturers quickly developed devices for clinical use. We have been using clinical PET/CT imaging since November 2001.

To better define clinical scenarios and patient populations in whom this new technology might provide a particular diagnostic benefit, we evaluated our findings in the initial 100 patients who had been imaged on the PET/CT. There was no selection bias based on the location of their tumor or past history. Two experienced nuclear medicine physicians compared attenuation-corrected FDG PET images and PET/CT fusion images with regard to certainty of anatomic localization of PET abnormalities, certainty of image interpretation, and diagnostic accuracy [17]. One hundred fifty-four lesions with abnormal FDG uptake were identified in this population. Based on their presumed anatomic location and intensity of FDG uptake, findings were classified as benign, malignant, or equivocal (indeterminate) on PET images alone. Once PET/CT fusion images were made available to the readers, the number of equivocal lesions decreased significantly from 50 to 22 (Table 2). In almost all cases

Table 2. Reduction of equivocal PET findings because of additional information provided by PET/CT fusion images

Body region	Number of equivocal lesions		% Decrease with PET/CT
	PET only	PET/CT	
Head and neck	14	6	57
Chest	15	12	25
Abdomen/pelvis	21	4	80
Total	50	22	56

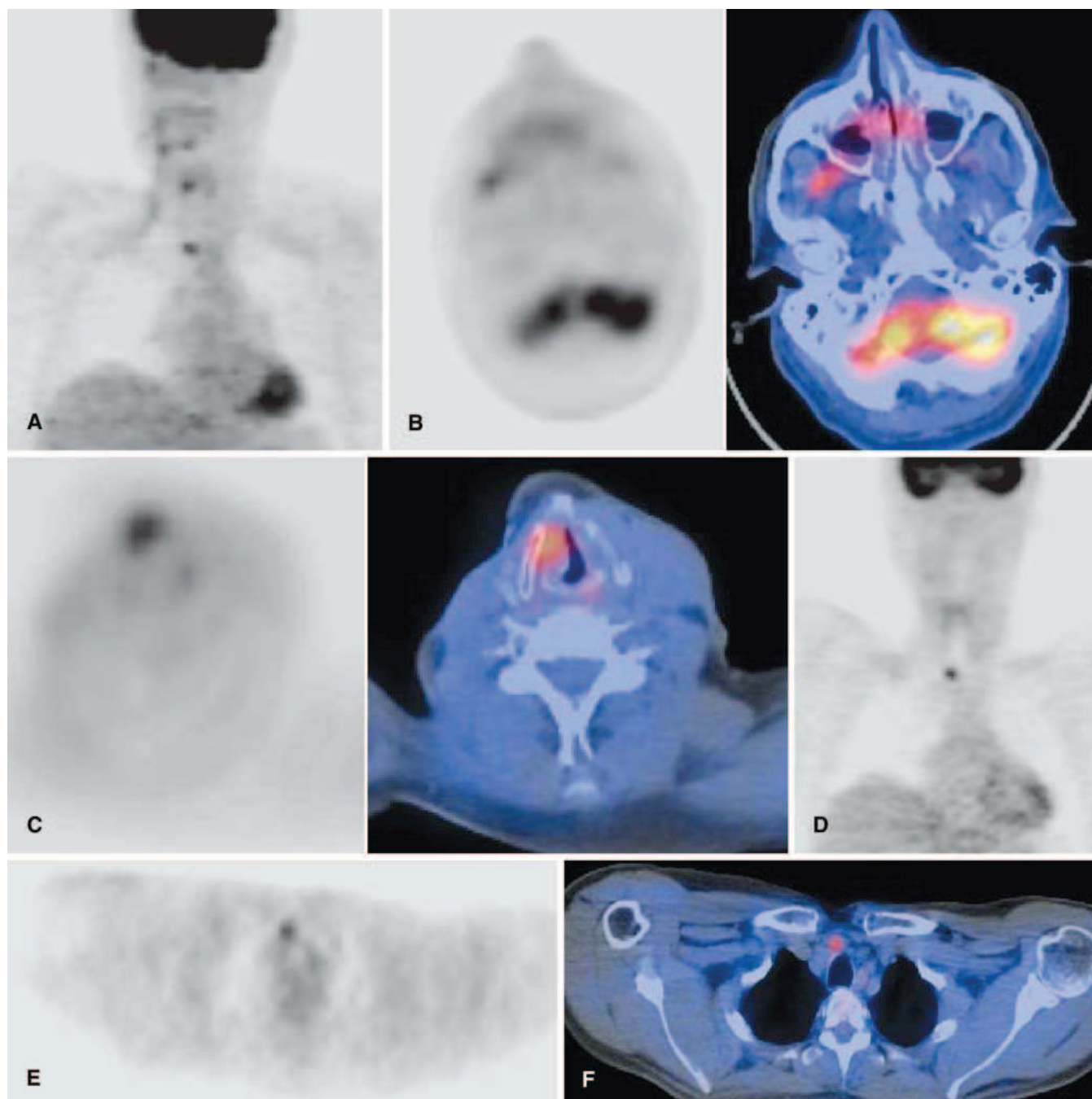


Fig. 2A–F. Images in a 45-year-old male with a history of nasopharyngeal carcinoma: status post radiation therapy and neck dissection. PET was ordered for surveillance. **A** Maximum intensity projection PET image shows several foci of increased FDG uptake in the neck. With the help of PET/CT fusion, these foci can be localized and characterized as **B** pterygoid muscle and **C** right vocal cord (patient had partial left vocal cord paralysis). (In **B** and **C**, PET/CT fusion images are shown on the *right*.) **D**, **E** Coronal (**D**) and transaxial (**E**) PET images again demonstrate a small focus of increased FDG uptake in the anterior superior mediastinum. **F** PET/CT fusion shows that this is located within a small pretracheal lymph node. A PET/CT-guided biopsy of this lymph node showed metastatic disease. The patient subsequently underwent chemotherapy followed by resection of paratracheal nodes. A follow-up study 6 months later was negative

this reclassification of findings was made possible by the additional anatomic information provided by the fusion images. Similar data have recently been reported by Israel and co-workers [18]: They compared PET and PET/CT in 134 cancer patients, recording differences in lesion detection, characterization, and exact localization. In this study, PET/CT led to retrospective discovery of 34 sites of malignancy. In addition, PET/CT findings were helpful in directing further diagnostic studies ($n=10$) and excluding a diagnosis of malignancy ($n=3$), and led to a change in the staging of the disease in three cases; overall, these alterations affected further management in 12% of patients. Similar findings were recently

also reported in a group of patients with rising tumor markers [19].

Our initial study demonstrated that PET/CT was particularly helpful in the head and neck as well as the abdomen/pelvis, i.e., areas with “complex anatomy.” These results likely confirm a “feeling” or “hunch” many nuclear medicine physicians and radiologists may have. In the neck, a number of normal structures demonstrate FDG uptake of variable intensity, including tonsils, tongue, salivary glands, soft palate, thyroid gland, neck and laryngeal muscles, spinal cord, and sometimes also brown fat tissue [20, 21, 22, 23] (Figs. 2, 3, 11). In the abdomen, a variable degree of FDG uptake can be seen in bowel loops [24], and there is excreted FDG in kidneys, ureters, urinary bladder, and sometimes (especially following transurethral resection of the prostate) also the prostatic urethra. One would therefore expect a particular advantage of PET/CT in these regions of the body. These findings were subsequently confirmed in two studies in patients with head and neck cancer as well as patients with abdominal and pelvic malignancies [25, 26]. Recent data indicate that imaging with combined PET/CT may be particularly useful in patients with head and neck cancer, for the staging for primary non-small cell lung cancer (NSCLC), and in patients with suspected recurrent colorectal cancer.

In our own study in patients with head and neck cancer, PET/CT revealed five malignancies that had been missed (considered benign or equivocal) by PET alone. In addition, 38 findings were classified as equivocal based on PET alone. With the addition of PET/CT fusion images, this number decreased by 53% ($P < 0.01$; Fig. 2). When equivocal findings were excluded, the accuracy was only slightly higher for PET/CT compared to PET alone (96% vs 90%; $P < 0.01$). This is not surprising since FDG PET by itself is already highly accurate for the detection of malignancies in the head and neck [27, 28, 29, 30]. However, the interpretation of radiologic studies as “equivocal,” in simply descriptive terms or in the form of a long list of differential diagnoses, is oftentimes clinically not helpful. In fact, equivocal findings frequently require further evaluation by other imaging modalities, clinical and imaging follow-up, or even biopsy.

In our study, the combination of PET and CT provided definitive information for image interpretation in a significantly greater number of patients (52/68 vs 38/68 with PET alone). The additional information provided by PET/CT altered the patient management in 18% of cases.

In many institutions, patients with lung cancer are the largest or one of the largest patient groups referred for PET imaging. It is therefore important to determine whether PET/CT might be of value in the staging of the disease compared with PET alone. Steinert et al. studied 49 patients with NSCLC [31]. PET, CT, CT plus PET correlated visually, and combined PET/CT were compared and a TNM stage was assigned prospectively to each imaging study. Extended surgical staging and histo-

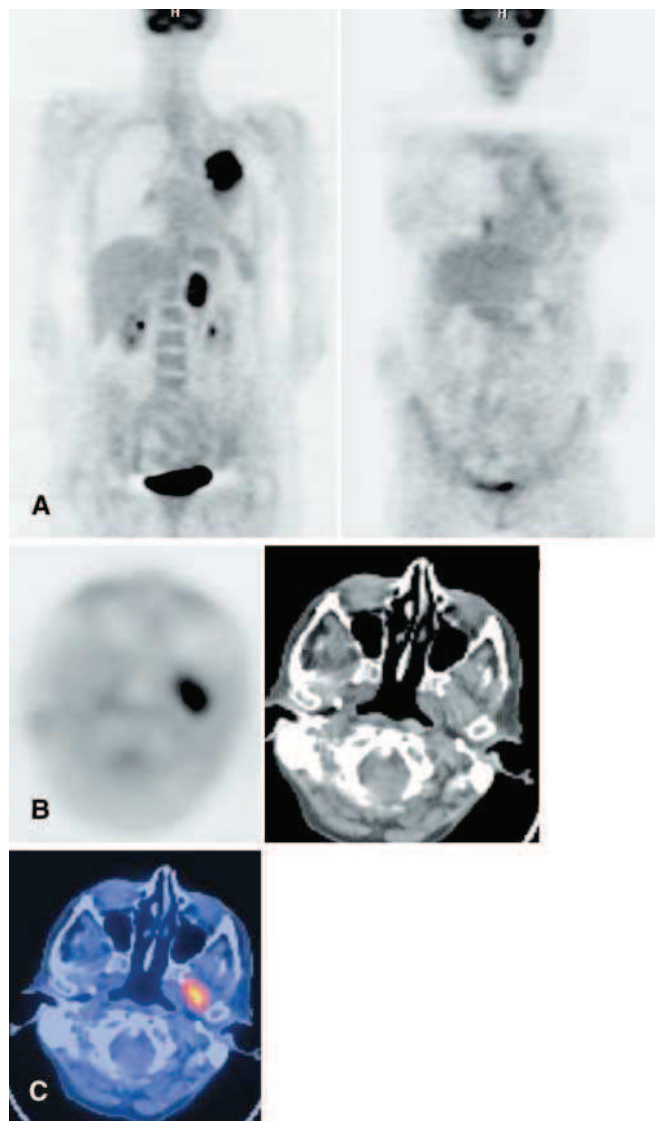
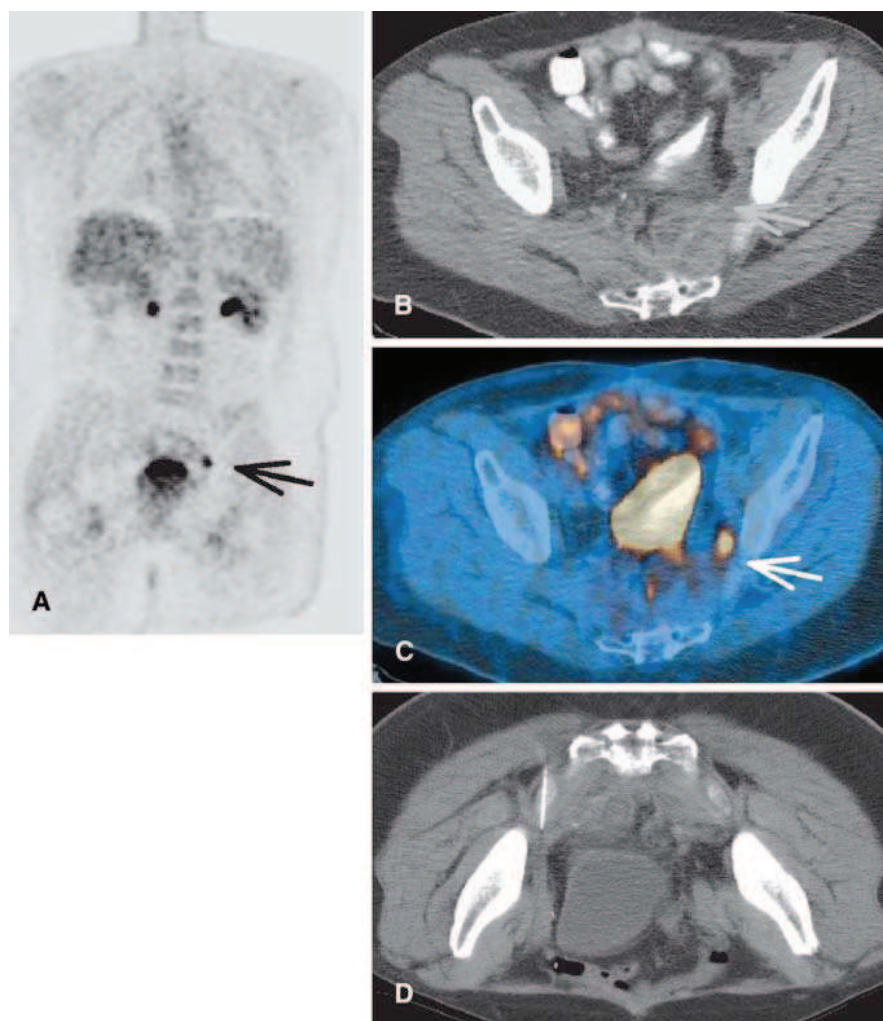


Fig. 3A–C. Patient with lung cancer and adrenal metastasis. **A** Coronal PET images show increased FDG uptake in the known lung primary and left adrenal gland (*left panel*) but also in the left side of the neck (*right panel*). **B** Transaxial PET and CT images at the site of this lesion. **C** PET/CT fusion proves that this activity is located within the pterygoid muscles, a physiological variant

pathology served as the standard of reference. Combined PET/CT provided additional information beyond that provided by visual correlation of PET plus CT in 20 of the 49 patients. Compared to histopathology, the T staging was correct with CT alone in 58%, with PET alone in 40%, with visual correlation of PET plus CT in 65%, and with combined PET/CT in 88% of cases. Conversely, the T stage was assigned incorrectly with CT alone in 22%, with PET alone in 20%, and with CT plus PET in 22%, but in only 2% with combined PET/CT. In addition, the number of equivocal findings was lower with PET/CT. PET/CT specifically improved the detection of chest wall invasion and mediastinal invasion by lung cancer.

Fig. 4A–D. Images in a patient with a history of colorectal carcinoma: status post resection; the patient now presented with rising CEA. **A** Coronal PET image demonstrates a small focus of increased FDG uptake in the left lower pelvis (*arrow*). **B** The transaxial CT without intravenous contrast shows increased soft tissue along the left pelvic side wall (*arrow*). On a prior diagnostic CT with oral and intravenous contrast, this was thought to represent non-specific postsurgical changes. **C** PET/CT reveals a small focus of abnormal FDG uptake at the left pelvic side wall (*arrow*). **D** PET/CT-guided biopsy proves recurrent disease



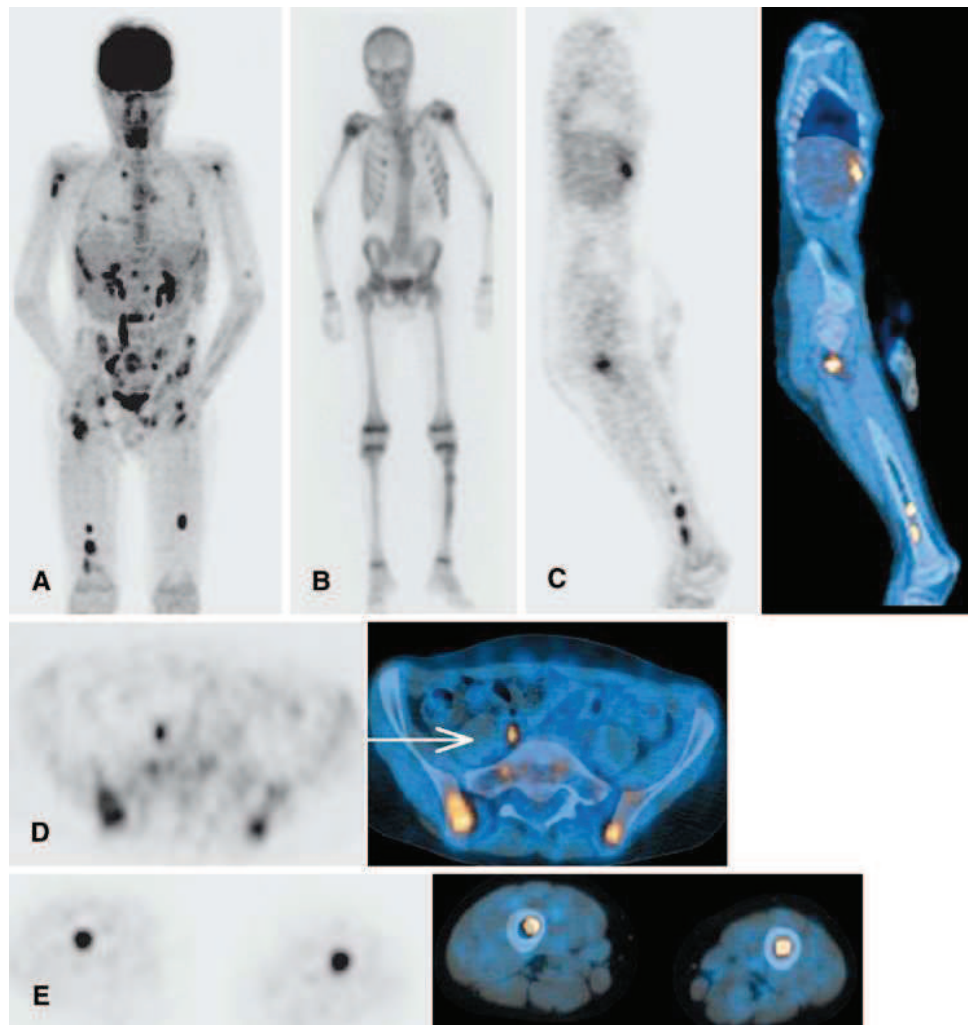
In the assessment of nodal metastases (37 cases with histopathological verification), PET/CT was also more accurate than CT or PET alone or PET plus CT with visual correlation. Somewhat surprisingly, the accuracy for nodal staging with PET alone was significantly lower than in many previous studies. Nevertheless, correct T and N stages were determined in a significantly greater number of patients when PET/CT was used. Moreover, PET detected eight extrathoracic metastases and correctly localized six of them; for the remaining two lesions the exact location could only be determined with combined PET/CT.

Burger et al. compared PET with PET/CT in 65 patients with primary or suspected recurrent colorectal carcinoma [32]. Histology or clinical follow-up served as the gold standard. The accuracy of image interpretation was significantly higher with PET/CT than with PET alone for detection of both recurrent disease and metastases in patients with primary carcinoma (97% vs 86% and 96% vs 72% respectively). In addition, the use of PET/CT resulted in less over- and understaging of these patients (10% and 31% respectively) and in a better in-

ter-observer agreement, compared with PET alone (kappa 0.74 vs 0.53). PET/CT may be helpful in the detection of recurrent malignancies (Fig. 4). It is well known that CT has a limited specificity following abdominal surgery or radiation therapy. A frequent problem is the characterization of soft tissue that has newly developed postsurgically or following irradiation in the presacral space or along the pelvic side walls (Fig. 4). If there is suspicion of recurrent disease based on PET and fusion images, PET/CT can also be used to guide biopsy in these patients (Fig. 4).

PET/CT is also helpful in the differentiation between osseous lesions and lesions in adjacent soft tissue. The differentiation between osseous and extraosseous lesions is a potentially important issue in the staging of many malignancies (for instance lung cancer and malignant lymphoma, in which the presence of osseous lesions indicates M1 or stage IV disease associated with a poorer prognosis and, therefore, usually necessitates a change in patient management). Akhurst et al. [33] studied 40 patients with a variety of malignancies; PET and PET/CT were compared in terms of their ability to determine the

Fig. 5A–E. Images in a 14-year-old boy with recurrent Ewing's sarcoma. The primary tumor had been resected from the left tibia 8 months earlier. **A** FDG PET MIP image demonstrates multiple foci with abnormal FDG uptake. **B** A bone scan only reveals increased MDP uptake in the left tibia, related to postsurgical changes, and two rib lesions. **C–E** Sagittal (**C**) and transaxial (**D, E**) PET images again demonstrate foci of abnormal FDG uptake, which the fusion image localizes to bone marrow. FDG PET images are shown on the *left*, and fusion images on the *right*. The *arrow* indicates excreted FDG in the ureter



exact location of foci with abnormal FDG uptake and to assess the likelihood of malignancy of these findings. Two nuclear medicine attending physicians and one inexperienced reader (a nuclear medicine resident) interpreted PET and PET/CT studies separately. Another attending physician, who was not involved in the interpretation of PET and PET/CT, independently determined the accuracy of study interpretation based on available histopathology or 7 months of clinical and imaging follow-up. For the two attending physicians, the accuracy of study interpretation increased only slightly with PET/CT, but the level of confidence and the number of lesions whose exact anatomic location could be determined increased significantly with PET/CT. Of note, PET/CT fusion images were of greatest advantage to the inexperienced reader, whose level of confidence in image interpretation and accuracy for anatomic localization improved from 18% to 84% and from 68% to 82% respectively (versus 80% to 99% and 82% to 96% for the attending physicians). These results obviously confirm an old truth in imaging sciences, namely that accuracy of image interpretation improves with increasing experi-

ence, but they also prove that the CT and PET/CT fusion images provide additional benefit even for the experienced reader. PET/CT fusion images are also helpful in demonstrating the exact location of lesions with abnormal FDG uptake in cases where the CT or a bone scan do not reveal an abnormality in the bones (Fig. 5).

A number of other clinical applications for PET/CT are currently under investigation; for instance, preliminary data suggest that PET/CT may be more accurate in the detection of metastases from ovarian carcinoma [34]. The group at the University of Pittsburgh reported that combined PET/CT is superior to CT alone in the staging and restaging of patients with cancer of the uterine cervix and those with ovarian carcinoma [35, 36]. Preliminary data from our own institution suggest that PET/CT has a diagnostic advantage over PET alone as well as contrast CT alone in pediatric patients with cancer (Fig. 5).

Future work may include the routine use of combined PET/CT for radiation treatment planning. Many institutions are already using PET for the planning of radiation treatment fields, in particular in the head and neck as

well as in patients with lung cancer. Although patient outcome can be improved significantly using a PET-based approach for radiation treatment planning [37], the current set-up, which involves transportation of the immobilized patient between nuclear medicine and radiation therapy suites as well as software-based fusion of two image sets that were acquired at different times with different equipment, is clearly suboptimal. Therefore, we expect that within the next few years combined PET/CT will become an essential part of radiation treatment planning in most larger institutions. Other potential applications for PET/CT include virtual colonoscopy or bronchoscopy or the study of cardiac anatomy and function, coronary anatomy and calcifications as well as myocardial perfusion and metabolism with one imaging device in one setting.

Image acquisition protocols

Patients are imaged following the standard radiotracer uptake period (for instance, 60 min for FDG). Initially, the low-dose CT scan is acquired (120 kVp, 80 mA, 0.8 s/rotation, 4 mm slice thickness). We do not administer intravenous contrast material for clinical PET/CT studies. For this reason and because of the lower dose (compared with standard clinical CT protocols), the image quality of the CT is slightly inferior to that of full diagnostic CT, but it is certainly sufficient for anatomic correlation. At our institution most patients are imaged by full diagnostic CT with oral and intravenous contrast as part of the regular clinical work-up or as part of research protocols. These CT scans are done in a different location, using various imaging protocols for different body regions and appropriate for the specific clinical question (for instance, dual-phase CT for evaluation of liver or adrenal lesions). We have made the decision that PET/CT cannot, at this time, replace any of these full diagnostic CT scans in our institution. In addition, our workload of approximately 25 PET/CT studies per day requires efficient patient throughput which likely could not be realized with implementation of various CT imaging and i.v. contrast injection protocols. It is also likely that a bolus injection of i.v. contrast, as practiced as part of the regular CT protocols, would interfere with the attenuation correction of PET images and therefore potentially cause inaccuracies in calculating local activity concentrations (SUV). However, other institutions face different challenges and have chosen a different approach. For instance, a low-dose CT can be performed first (for attenuation correction of PET images), followed by the emission PET scan, followed by a full diagnostic CT with intravenous contrast using specific CT protocols. In this case, the complete work-up, for instance for lung or colorectal cancer, can be completed in one imaging session. In the end, which protocol is preferred will depend on local conditions and institutional workflow demands.

We expect that, in the near future, methods will be developed that can correct for higher CT densities related to the presence of intravascular contrast. Once these methods become available, it is quite likely that intravenous contrast agents (in somewhat lower concentration than in current standard CT protocols) will be used for PET/CT in certain groups of patients, in particular those with head and neck cancer.

In the abdomen, despite PET/CT fusion, it may sometimes be difficult to determine the exact location of foci with increased FDG uptake if no oral and/or intravenous contrast is administered. We have conducted a series of phantom studies and have concluded that diluted oral contrast (for instance, 2.1% barium sulfate) does not usually affect the quality of attenuation-corrected PET images or the accuracy of SUV measurements. Diluted oral contrast can therefore be administered as part of the PET/CT. In patients who refuse oral contrast, the oral administration of plain water ("hydro-CT") provides a reasonable alternative for distending stomach and bowel loops, at least in the upper and mid abdomen.

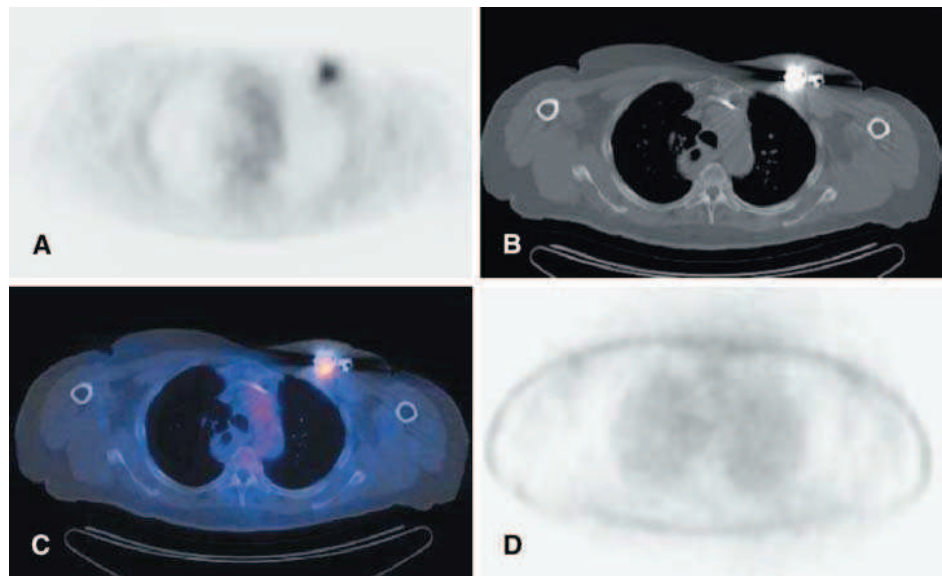
Image interpretation

We routinely review the PET images first, and ideally also a maximum intensity projection (MIP) image of the PET data set. We then use the CT and PET/CT fusion images for further evaluation of PET abnormalities, determine their exact anatomic location, and classify findings as benign, equivocal, or malignant. At the same time potential artifacts on PET and PET/CT fusion images are identified (see below). Depending on the reader/attending physician, the CT images are also reviewed for obvious abnormalities that were not detected by PET and may or may not be related to the clinical indication for the current study. Such abnormalities detected on CT include, for instance, aortic or iliac artery aneurysms, gallstones, kidney stones, lung nodules, or opacities that do not show uptake of FDG. Comparison with previous studies is obtained by using the PET/CT workstation or the PACS with linked display of PET and CT images of a prior PET/CT. It should be noted that some institutions have set up joint image interpretation sessions with nuclear medicine physicians and CT radiologists. Others have established a formal, if limited, interpretation of the low-dose CT component of PET/CT.

Potential pitfalls related to image artifacts and misalignment between CT and PET data sets are discussed below. It needs to be emphasized that fusion images should be interpreted with caution. With the necessary critical distance and clinical judgment, most if not all of these artifacts (including misplaced PET findings from liver into lung on fusion images: see below and Fig. 10; reference [38]) can be detected and a proper study interpretation can be provided. It is therefore important to always evaluate the original PET and CT images indepen-

Fig. 6A–D. Pacemaker artifact on attenuation-corrected PET and fusion images. **A** Attenuation-corrected transaxial slice of the upper chest in FDG-PET, showing a focus of apparently increased tracer uptake in the left anterior chest wall.

B, C The corresponding CT (**B**) and PET/CT fusion (**C**) images show that this “hot spot” localizes to the pacemaker. **D** The non-attenuation-corrected PET image is completely normal



dently; fusion images are frequently helpful, but should only be interpreted in conjunction with and after review of the original data sets for PET and CT.

Potential pitfalls and artifacts

Different types of normal variants and artifacts in PET imaging are well reported and not within the scope of this review. There are, however, artifacts that are recognized only with combined PET/CT. These artifacts can be divided into three groups: attenuation correction artifact, motion artifact, and the CT truncation artifact. Recently, a number of case reports have been published in this regard [20, 21, 22, 34, 39, 40, 41, 42, 43, 44, 45, 46, 47, 48, 49]. We shall, therefore, concentrate on the underlying principles and methods of how to avoid or at least recognize these artifacts.

Attenuation correction artifact

In PET/CT the CT images are used for attenuation correction of the PET emission data to obtain the final images. Since there is a great difference in the photon energy between the annihilation photon of the positron emitters (511 keV) and the photons from the CT X-ray tubes (about 100 keV), algorithms have been designed to correct for the difference in attenuation of the different photon energies in different tissues and thereby ensure the proper attenuation correction of the PET emission images. However, when the radiodensity is significantly higher than the range normally seen in human tissue, over-correction can occur, resulting in hot spots in the final images.

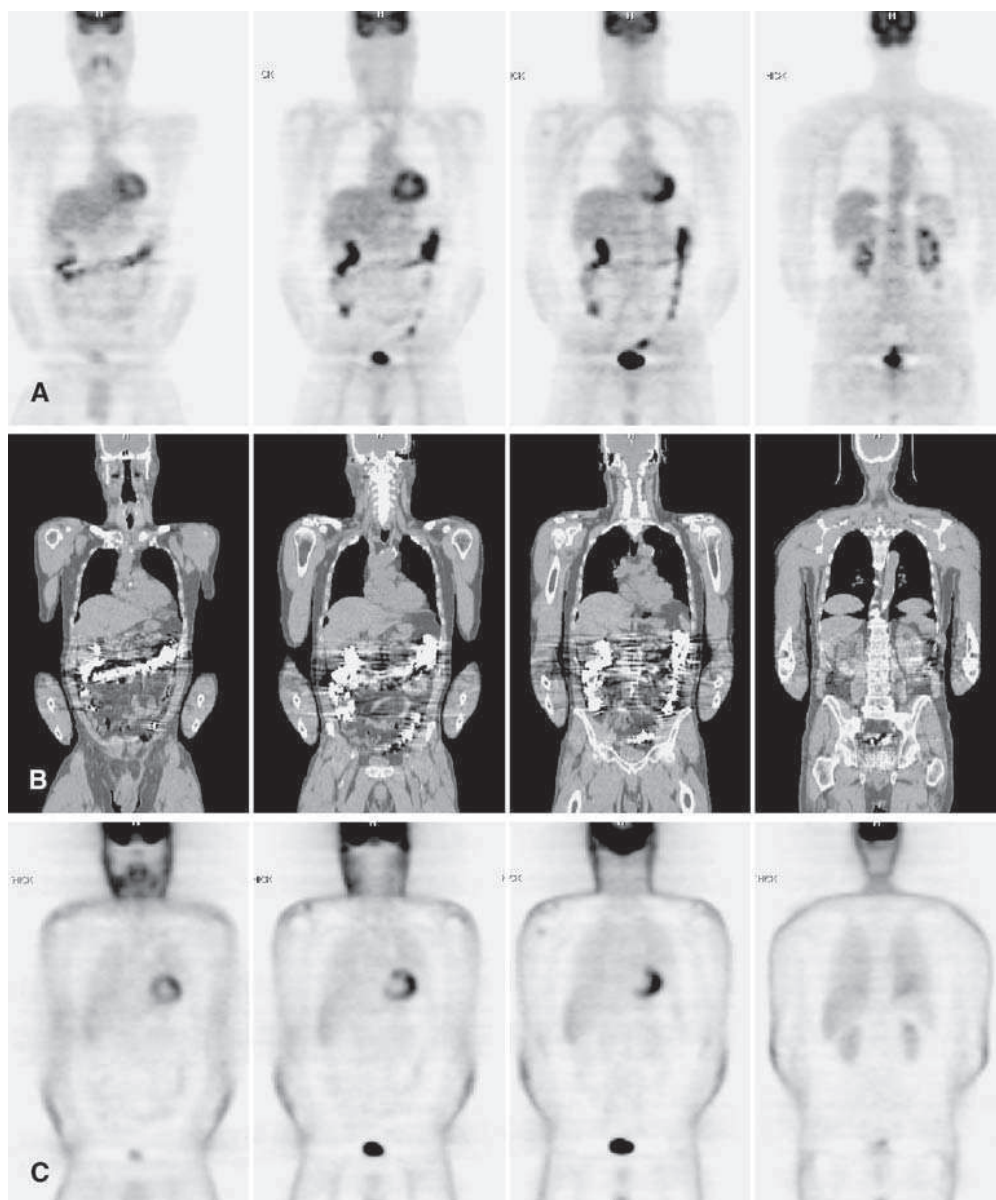
The most common attenuation artifact results from metallic implants in the body [46, 47]. A common exam-

ple is the pacemaker (Fig. 6), which is very radiodense on CT images. On the attenuation-corrected images it appears as a hot spot in the subcutaneous tissue and can easily be misinterpreted as representing malignancy or inflammation. However, the non-attenuation-corrected PET image clearly shows that there is normal FDG uptake in this area and that the hot spot seen in the final image is artifactual.

Another common attenuation artifact results from CT contrast material. Oral contrast that is normally used for CT imaging is of low radiodensity and does not cause any artifact in the PET images when given within a few hours prior to PET/CT. However, with time barium-based oral contrast becomes compacted in the large bowel and its radiodensity increases significantly. This usually happens when the patient had a CT scan with oral contrast one or two days earlier. The resulting attenuation artifacts may mimic diffuse colitis or colon cancer (Fig. 7). The barium used in radiologic examinations of the GI tract (barium enema or barium meal) is considerably more concentrated than that used in CT scans (almost 100 vol.% as compared to approximately 1.2–2.1 vol.%) and will definitely cause attenuation artifacts, regardless of the time interval between those studies and PET/CT. A characteristic beam-hardening artifact can be noted on the CT images, and the non-attenuation-corrected PET images are necessary to confirm or rule out abnormal FDG uptake due to disease involvement (Fig. 7). In contrast, diluted oral contrast does not create image artifacts and does not significantly alter the quantitative assessment of regional radiotracer concentrations, such as the SUV, as long as the CT attenuation value from oral contrast is lower than 400–500 Hounsfield units (own data and reference [50]).

Intravenous contrast is very radiodense (usually 300 mg I per 100 ml). It can cause significant CT arti-

Fig. 7A–C. Barium contrast artifact on FDG PET. **A** Attenuation-corrected coronal PET images demonstrate apparently increased FDG accumulation throughout the entire colon. **B** The corresponding CT slices show dense barium in the large bowel, raising the possibility of an attenuation correction artifact. **C** This was confirmed on non-attenuation-corrected PET images, which show only normal bowel activity



facts (and, therefore, attenuation correction artifacts) when the CT images are acquired early after intravenous injection, when the contrast material is still in bolus form in the large veins, usually the superior vena cava or the subclavian vein of the side with the intravenous access [43]. The resultant artifactual FDG activity can be misinterpreted as tumor involving the mediastinum or the brachial plexus [43]. Again, the beam-hardening artifact on the CT images indicates that an attenuation artifact may be present, and the uncorrected PET images are necessary to confirm or rule out abnormal FDG activity.

Motion artifact

A motion artifact results when there is patient or organ movement between the PET emission scan and the CT

scan. Even though the scans are done in close temporal proximity, the different duration of acquisition and the difference in spatial resolution of the transmission and emission scans can cause minor misregistration. Since the CT scan is used for attenuation correction, misregistration causes over- or under-correction of the PET emission data and, thereby, areas of artifactually increased or decreased FDG activity. This happens more frequently in the head and neck or in the extremities, where there is greater freedom of motion. The same phenomenon occurs with dedicated PET tomographs, where rod sources are used to obtain the transmission scan. However, using PET/CT, the artifact becomes more obvious because of the better anatomic localization on fusion images (Fig. 8).

Another type of motion artifact that occurs with PET/CT is due to motion of the internal organs just above and below the diaphragm during respiration. The

Fig. 8A–C. Head motion artifact. **A, B** Transaxial CT image (**A**) and PET emission image (**B**) of the same slice show change in orientation of the head between the PET and CT images. **C** The resulting attenuation-corrected image demonstrates apparently decreased tracer uptake in the left side of the face (*arrow*), which is the result of under-correction of photon attenuation in that region

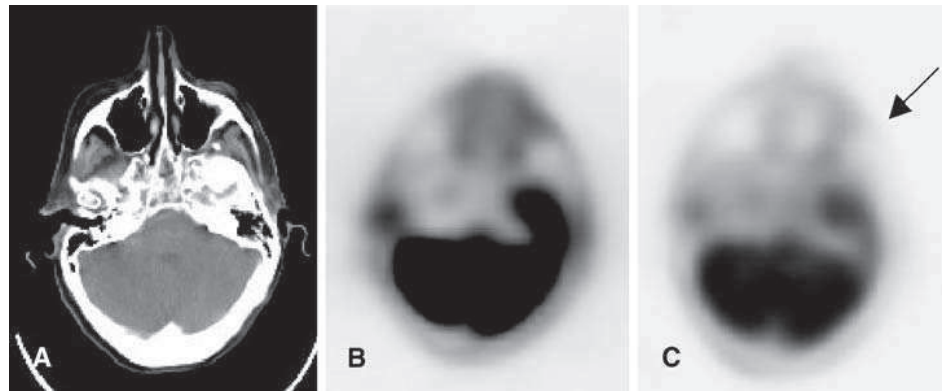
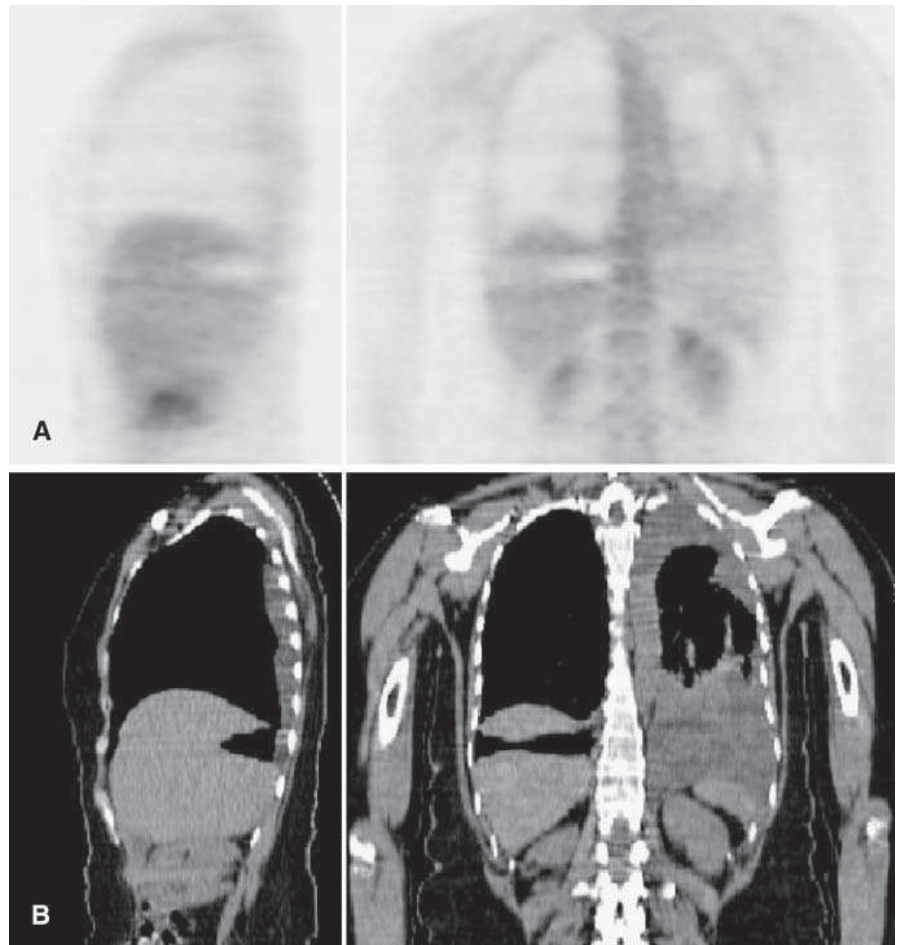


Fig. 9A, B. Respiratory motion artifact. **A** Sagittal and coronal PET images. **B** Corresponding CT images of the same position. The dome of the liver appears partially detached from the rest of the liver



PET emission scan requires several minutes per bed position. Therefore, on PET images movement of the diaphragm and internal organs will cause slight blurring or smearing, that is, the borders/contours of the diaphragm and the liver are smoothed out and appear to be at the neutral position. During the CT component of PET/CT imaging, we instruct patients to maintain shallow tidal breathing, so that the diaphragm and liver will be in, or close to, the neutral position, thereby avoiding misalignment between organ position on CT and PET images. If

the patient were to take a deep breath at the time of the CT scan, the position of the internal organs in the vicinity of the diaphragm would be different from that on the PET emission images, and this misalignment would cause errors in attenuation correction. There may be minor mismatches in location and organ size of the liver and spleen between the CT and PET images, with the liver appearing slightly cephalad and smaller on the PET images [51]. Occasionally part of the liver dome appears to float over the diaphragm (Fig. 9). More importantly,

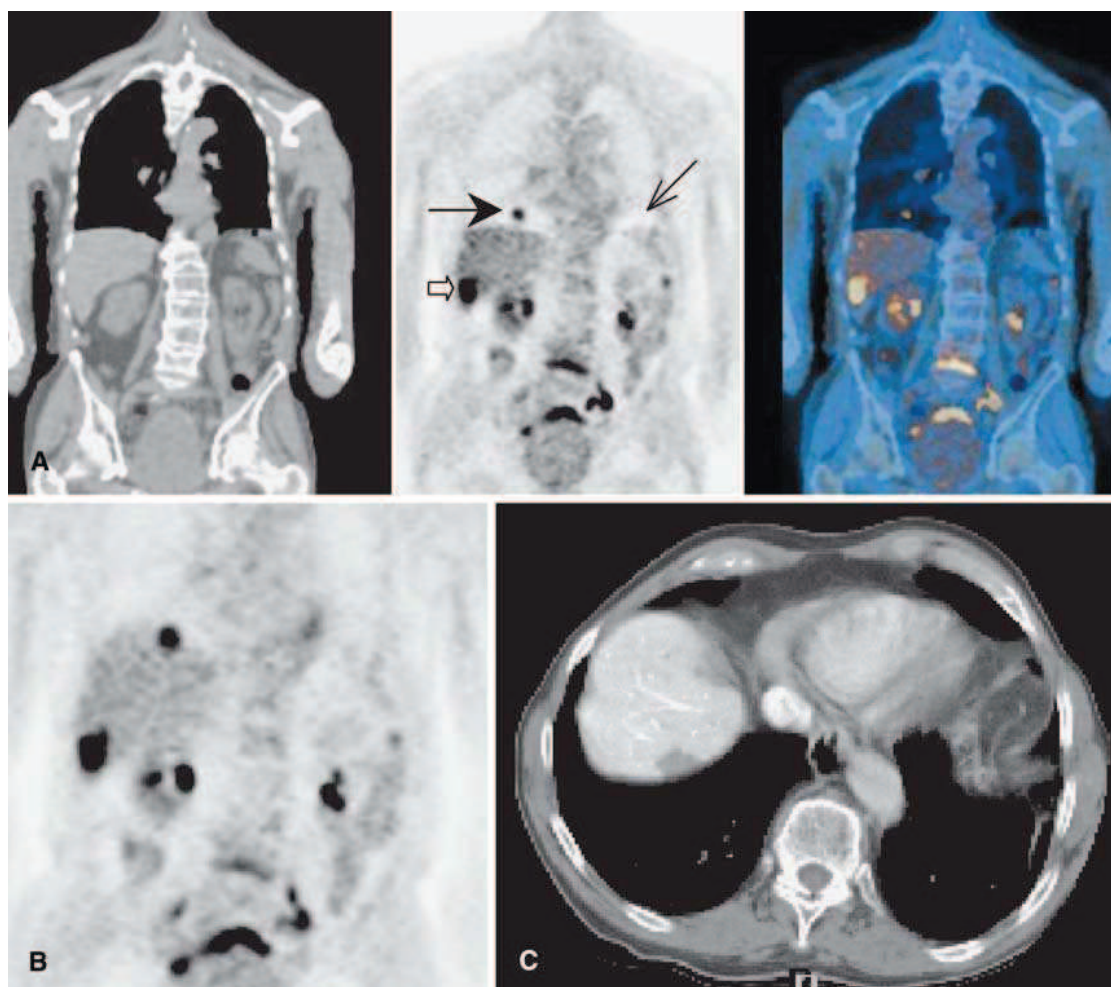


Fig. 10A–C. Respiratory motion artifact in a patient with liver metastases from colon cancer. **A** Coronal CT image (*left*), attenuation-corrected PET image (*center*) and PET/CT fusion image (*right*). There is a large focus of increased FDG activity in the inferior right lobe of the liver (*open arrow*) and a small focus at the base of the right lung base (*long horizontal arrow*). **B** In the non-attenuation-corrected PET image, the hypermetabolic focus is no longer located in the right lung base, but rather in the dome of the liver. **C** Contrast CT confirms that the abnormality is located in the liver, and that there are no lung nodules. Note also the crescent-shaped area of relatively decreased FDG accumulation at the diaphragm (*diagonal arrow* in **A**), another common pattern of respiratory motion artifact

this can cause hypermetabolic lesions in the dome of the liver to appear to be located in the lower lung field (Fig. 10). While the first artifact is rather obvious and easily recognizable, the latter requires more awareness and attention, in order to avoid misdiagnosis of “metastases” in a normal lung [38] or (even more difficult) in a patient with lower lobe nodules which by themselves do not demonstrate abnormal FDG uptake.

Another pattern of respiratory motion artifact shows a cold area at the interface of the liver/spleen and the lungs

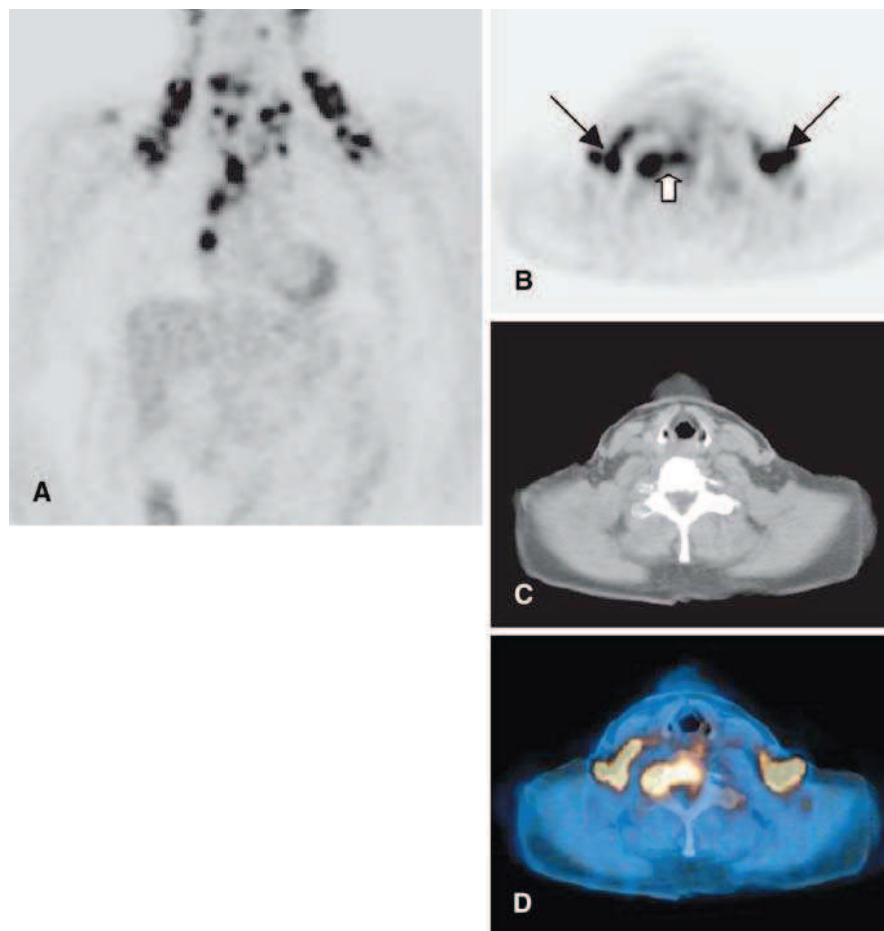
[38] (Fig. 10). Clinical correlation, evaluation of the non-attenuation-corrected images, and head to head comparison of CT and PET images (rather than evaluation of PET/CT fusion images alone) are helpful in identifying this artifact.

Different maneuvers have been attempted to minimize the effect of the respiratory motion artifact. Breath holding at the end of normal expiration during CT scanning has been reported to cause the least problem [52, 53]. However, even with quiet tidal breathing, major respiratory motion artifacts are infrequent and usually do not cause diagnostic problems [41, 51].

CT truncation artifact

Because of the extended imaging time and to increase patient comfort, PET data are usually acquired when patients have their arms positioned along the trunk. This is a problem for CT because the axial field of view (AFOV) of the CT scanners is only 50 cm, so that often-times parts of the arms or shoulders are outside the AFOV. This results in truncation artifacts because the CT reconstruction algorithm does not take into account any attenuation of X-rays by tissues outside the FOV.

Fig. 11A–D. FDG uptake in fat tissue. Images in a 56-year-old female with lung cancer. **A** Coronal PET images show multiple foci of increased FDG uptake in the mediastinum, supraclavicular regions, and neck. In the mediastinum, this corresponds to enlarged lymph nodes on CT (not shown here). **B** Transaxial attenuation-corrected PET images of the neck. **C, D** Corresponding CT (**C**) and PET/CT fusion (**D**) images reveal FDG uptake in soft tissue and bone metastases (*open arrow*) in addition to intense FDG activity in the adipose tissue (*black arrows*). FDG accumulation in fat tissues in the neck and supraclavicular region has been described recently. The pattern has gained some notoriety, and FDG uptake in these regions is now frequently dismissed as a normal variant. This case serves as a reminder that true pathology and normal variants can co-exist in one image set, which can easily be diagnosed by PET/CT fusion



Truncation artifacts appear as fine wavy lines along the long axis of the patient, best seen in sagittal projections, or as fine horizontal stripes, best seen in coronal sections. Although the quality of the CT images is degraded by this artifact, the attenuation-corrected PET images are not appreciably affected.

Truncation artifacts can be eliminated by positioning the patient so that the arms are entirely within the CT AFOV. This can be achieved either by securing the arms over the abdomen or, if shorter scan times are possible with new machines, by placing the arms above the head. The latter position is better for imaging of the torso but patients usually do not tolerate it for longer than 10 or 15 min.

FDG uptake in adipose tissue: pitfalls in image interpretation elucidated with PET/CT

Investigators have long noticed the occasional appearance of a curvilinear, sometimes nodular, pattern of intense FDG activity in the neck and supraclavicular regions bilaterally in patients without radiologic or clinical evidence of disease in those areas (Fig. 11). Because of its configuration and the observation that this “abnormality” resolved on repeat studies after pretreatment with

oral diazepam, a muscle relaxant, it was widely accepted to represent muscle uptake of FDG secondary to patient anxiety [54].

Surprisingly, on PET/CT fusion images this intense FDG uptake is clearly shown to be located in the adipose tissue of the neck and supraclavicular regions (Fig. 11) [20, 23]. Moreover, it was noted that in some patients with this FDG uptake pattern, intense tracer accumulation was also present in adipose tissue in the mediastinum, axillae, and perinephric regions. It is now believed that this phenomenon in fact represents FDG uptake in brown adipose tissue. Because of the intensity of FDG uptake, it can cause false positive PET interpretations. Conversely, true abnormalities, which exhibit increased FDG uptake, can be obscured by the intense tracer activity in adipose tissue of the neck and supraclavicular regions (Fig. 11), resulting in false negative interpretations.

Based on recently published data, this normal variant in FDG uptake can be observed in 2–3% of patients undergoing FDG PET. The true nature of the FDG activity can be readily ascertained with PET/CT fusion images. For readers without the benefit of the PET/CT fusion images, it is important to be aware of this normal variant to avoid both false positive and false negative interpretations. If intense FDG uptake in the above regions is not-

ed and there is no clear clinical or radiologic correlation, FDG uptake in brown fat tissue should be considered. If clinically relevant, imaging with PET/CT or a repeat study after pretreatment with oral diazepam to reduce uptake in brown fat can be helpful (benzodiazepine receptors have been identified in brown fat).

Summary: benefits of PET/CT

There are at least two obvious advantages of PET/CT over PET alone: shorter total imaging time per patient and improved anatomic localization of lesions. A major reason for the introduction of PET/CT at our institution was the ability to shorten the average study time by 20–30 min, because the CT data can be used for attenuation correction, thus eliminating the need for the 3 min/bed position transmission scans. In fact, with the introduction of PET/CT we have been able to increase the number of patients imaged during an average 8-h shift by approximately 30–40%. Shorter imaging time also improves patient comfort. PET/CT fusion imaging not only improves interpretation of PET images, but also enhances the information available from the CT scan. Finally, PET/CT fusion images can be instrumental in guiding biopsies (Fig. 4), and in the future likely also for radiation treatment planning.

Last but not least, PET/CT fusion images, as compared to PET emission images alone, are more intuitive, appealing, and convincing to many surgical and medical oncologists. In particular in cases without corresponding abnormality on (regular contrast) CT, an area of abnormal FDG uptake on PET images is more likely to affect clinical decision making when the abnormality can be clearly localized on the PET/CT fusion images (Fig. 2).

Radiation dosimetry for PET/CT

Based on the model in ICRP 53 and using a dynamic bladder model with 4.8-h voiding, the effective dose equivalent from intravenous injection of 555 MBq FDG (15 mCi) is approximately 16.5 mSv (0.03 mSv/MBq) [55]. Doses to individual organs from intravenously injected FDG can be found at the web address <http://www.internaldosimetry.com/freedoseestimates/adult/linkedpages/f18FDG.html>. Using 140 kV, 80 mAs, and 0.8 s/rotation for the GE LightSpeed CT, the additional dose from the low-dose spiral CT is approximately 10 mSv (own measurements). The total effective dose equivalent for a whole body PET/CT is therefore approximately 26 mSv.

Based on the published results, this compares favorably with 15.6–21.4 mSv for a spiral CT of the chest [56] or 17.8–22.2 mSv for a spiral CT of the abdomen [57] for the same kind of CT scanner. It is obvious that the dose from PET/CT is well within the range of estab-

lished radiologic studies. Future studies will have to demonstrate whether PET/CT (with a low-dose CT component) can replace the full diagnostic CT with intravenous contrast in certain patient groups.

Implications for the nuclear medicine community

An ongoing debate: why do we need PET/CT?

It appears that the nuclear medicine and radiology community is divided over this issue into three parties or blocks: supporters, critics/opponents, and impartial observers. Accordingly, the presentation of first results with clinical PET/CT during last year's scientific meetings (SNM, EANM, RSNA) was surrounded by a surprising controversy.

Some critics questioned the clinical relevance of the data presented and the need for "inline" PET/CT systems, mostly referring to their individual or institutional experience with simultaneous display of PET and CT data on adjacent monitors or self-made fusion software programs and claiming that similar if not identical results could have been obtained with "mental" or software image fusion of separate CT and PET data sets. It is interesting, on the other hand, that all users of PET/CT (the overwhelming majority of whom have no commercial interest in the product) vigorously supported the clinical use of this technique.

Although "mental" or software image fusion is certainly advantageous over a "blind" interpretation of PET studies, it is quite obvious that these approaches have severe limitations. While it is simple to compare a 2-cm lung nodule on an outside CT with findings on a PET study, the same does not hold true in cases with multiple adjacent CT abnormalities but fewer PET abnormalities (or vice versa), in cases without obvious abnormality on CT (e.g., bone marrow metastases, metastases in small lymph nodes, intestinal malignancies that do not cause obvious thickening of the bowel wall), or in cases with large areas of nonspecific contrast enhancement on CT but smaller abnormality on PET (e.g., recurrent carcinoma in the irradiated neck). We have certainly seen examples for all of these scenarios, and in many of these cases, PET/CT fusion images were instrumental in guiding subsequent biopsies or therapy. Based on many years of experience with software fusion programs and having now worked with PET/CT for 1 1/2 years, we have concluded that inline PET/CT is far superior to any attempt at "visual" or "mental" image fusion as well as software fusion of image sets from different machines. Software fusion works reasonably well in regions of the body where no motion occurs, such as the brain. It does not work well in the head and neck and abdomen and pelvis. Finally, and perhaps most importantly, there is the question of why a patient should have to undergo two sepa-

rate imaging studies (CT and PET) at different times (sometimes different days) and in different locations, if the same diagnostic information can be obtained with one combined PET/CT study.

Some have argued that experienced nuclear medicine physicians rarely need additional anatomic information for the interpretation of PET scans. To some degree this reminds us of the old saying: "Order is only for beginners, the genius can master the chaos". While it is generally true in medicine that a number of potential pitfalls can be avoided by the experienced physician, there are certainly also many examples of how improvements in imaging technology have contributed to the progress that medicine as a whole has made during the past 50 years. In fact, while the clinical usefulness of PET itself has rarely been questioned, its true diagnostic value (as compared with other radiologic or nuclear medicine imaging techniques) has been fully recognized only recently with the broad approval of FDG PET imaging for a number of malignancies by the Centers for Medicare and Medicaid Services (CMS) in the United States and by many European insurance carriers.

The following are questions that have been frequently raised with the clinical introduction of PET/CT: How often does PET/CT fusion improve physician confidence and clarity of PET image interpretation? How often is it essential in avoiding mistakes? How often is it instrumental in guiding patient management? Our answers are based on currently available publications. It appears that PET/CT provides better anatomic localization of PET abnormalities in up to 50% of cases and improves the quality and accuracy of reporting in at least 50% of lesions whose clinical significance cannot be determined based on PET alone [17]. In our study in patients with head and neck cancer, 6% of findings represented either cancer that was detected only by PET/CT fusion images or normal variants erroneously considered to be cancer on the basis of PET alone [25]. Finally, several studies have reported that PET/CT affects patient management in 18–25% of cases [18, 25, 31].

It needs to be emphasized that these data should be interpreted based on reasonable expectations: As stated recently by Ell and von Schulthess, "as PET is already good [that is, has a high accuracy], PET/CT cannot be expected to have a relevant impact in every second patient, but early experience suggests that it may have an impact in every fourth or fifth patient" [58]. This is in fact in concordance with the data outlined above.

Who needs PET/CT?

The brief answer is: probably not every institution, clinic, or practice that is using PET imaging. The more detailed answer depends on the patient population served in any given imaging center. Most tertiary care and cancer centers will find PET/CT extremely valuable. Converse-

ly, not every PET clinic may need this new technology, as complicated or advanced malignancies tend to be referred to tertiary care centers. In many patients who have had a complete response to chemotherapy or radiation therapy or who are considered surgically cured, it may be possible to perform routine follow-up studies with regular PET imaging.

Is PET/CT better than PET alone?

The answer is yes, and there are now several studies to support this conclusion. Is PET/CT better than CT alone? The answer is that PET alone is already proven to be more accurate than CT in a number of clinical scenarios, for instance for staging of lung and colorectal cancer, lymphoma, and head and neck cancer as well as for detection of recurrent disease [59, 60, 61]; therefore, such comparison is beyond the point. Hence the debate is circling around the question: Is PET/CT better than "PET plus CT" (with PET and CT images being acquired separately, on separate equipment at different time points)? The answer is very likely "yes," but this remains to be proven in larger, prospective studies. Such systematic comparisons of "PET plus CT" versus "combined PET/CT" should be performed in a prospective manner and in well-defined patient populations. Data analysis should not only focus on accuracy, but should also include level of confidence in study interpretation and physician's time spent on interpreting CT, PET and CT plus PET as compared to PET/CT alone. Certainly, the near simultaneous acquisition of PET and CT images reduces (a) problems related to misalignment and changing position of lesions, (b) potential changes in pathology in the time interval between PET and CT, (c) time and personnel necessary for software fusion of separate image sets. Certainly, PET/CT also improves patient throughput and clinical acceptance of PET findings, in particular in cases with no abnormality or equivocal findings on CT.

Financial considerations

Critics of PET/CT sometimes refer to the considerable costs. Indeed, current PET/CT systems are offered by vendors at approximately 2 million \$. However, this price is likely (and, in fact, bound) to decline as time goes by and clinical acceptance and widespread use of PET/CT systems increases. Patient throughput for PET studies can also be improved, owing to an average time saving of 20–30 min per patient. This is because the CT data can be used for attenuation correction, thus eliminating the need for the 3 min/bed position transmission scans. The time to amortization depends on the patient load and on whether the equipment is used for PET/CT only or PET/CT as well as full diagnostic CT (with oral and intravenous con-

trast). Von Schulthess has provided a rough estimate of additional costs, but also potential savings, associated with PET/CT imaging [62]. Although this remains to be proven, PET/CT has the potential to be cost-effective by avoiding follow-up imaging studies prompted by equivocal PET findings, by guiding biopsies to areas most likely to provide diagnostic material (Fig. 4), and by tailoring therapy to abnormalities that were detected as such only by PET/CT fusion (Figs. 2, 11). Finally, it is conceivable that PET/CT can replace full diagnostic CT (with i.v. contrast) in certain patient groups.

Suggested training requirements

Since PET/CT (and perhaps also SPET/CT) is likely to become a very important modality in oncologic imaging, current and future nuclear medicine trainees, as well as established nuclear medicine physicians who are interested in PET/CT, should be encouraged and given the opportunity to study the basics of CT imaging. Prospective nuclear medicine residents should also be given the opportunity to learn PET/CT during their training or, at least, to spend several weeks of rotation in CT imaging. Obviously, in order to localize PET abnormalities on CT, one needs to have a fairly comprehensive understanding of CT anatomy. In institutions where radiologists are responsible for generating a separate report on the CT portion of the PET/CT study, nuclear medicine physicians should use this as a learning opportunity, ideally during joint image interpretation sessions. Similarly, if radiologists want to provide a comprehensive interpretation of PET/CT studies, they will benefit from additional training in PET imaging (including potential artifacts, methods, and limitations of various measurements of tissue activity concentration), radiotracer kinetics, and tumor biology. Such additional training for radiologists will become particularly important with the increasing clinical use of new radiotracers that address different aspects of tumor biology, such as FLT, radiolabeled amino acids, acetate, choline, and receptor binding molecules (e.g., FDOPA, dopamine, raclopride, DOTATOC).

Conclusion

PET/CT is a new imaging technology that is here to stay. While much work remains to be done, the available data clearly suggest that PET/CT decreases imaging time spent per patient and (even for the experienced reader) significantly reduces the number of equivocal PET interpretations. PET/CT also has the ability to improve accuracy of PET image interpretation and to affect clinical decision making, thereby improving patient management. The nuclear medicine community should approach this new technology not from an ideological point of view but with an open mind and focus on its clinical use-

fulness. The decision regarding whether PET/CT should be part of the equipment in a given nuclear medicine or radiology practice largely depends on the specific patient population. Certainly, most university clinics or tertiary care centers will benefit from PET/CT. We are confident that much of the present skepticism will subside once critics have had the opportunity to clearly "see" the many advantages of combined PET/CT over either PET alone or conventional image fusion approaches: one image says more than thousand words.

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