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Fundamentals of Oncologic PET/CT

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CHAPTER 1

Introduction to FDG PET/CT

18F-flourodeoxyglucose positron emission tomography/computed tomography (FDG PET/CT) provides noninvasive metabolic and anatomic imaging. The radioisotope, flouride-18, has a short half-life allowing for imaging with limited patient dose. Fluoride-18 is used to chemically replace a hydroxyl group on glucose, and the resultant FDG is taken up into cells analogous to glucose. As tumor cells often uptake more glucose than normal tissues, FDG allows effective imaging of tumors.

The majority of this textbook focuses on hybrid FDG PET/CT for oncology. More than 1.7 million PET examinations are performed each year in the United States. There are several interesting facts about these PET examinations.

1 Greater than 95% of PET scans are performed with FDG as the radiotracer.

2 95% of PET scans are performed for oncology (3% for cardiology, 2% for neurology).

3 Greater than 95% of PET scans are performed as hybrid PET/CT studies. (Data from IMV 2015 PET Imaging Market Summary Report, http://www.imvinfo.com/index.aspx?sec=pet&sub=dis&itemid=200083.)

Let's look at each point.

1. Greater than 95% of PET scans are performed with FDG as the radiotracer.

   FDG is by far the most commonly used radiotracer for PET imaging. There are other PET radiotracers that are U.S. Food and Drug Administration (FDA) approved for imaging, and many more which are not FDA approved, but the vast majority of PET scans are currently performed with FDG as the tracer. Thus the majority of this book focuses on the interpretation of FDG PET. The final chapter introduces other radiotracers with strong potential for increased utilization in the future.

2. 95% of PET scans are performed for oncology.

   There are important applications of PET for cardiology and neurology; however, the vast majority of PET examinations are performed to evaluate patients with malignancy. Thus this book focuses on oncologic FDG PET.

3. Greater than 95% of PET scans are performed as hybrid PET/CT studies.

   There are several reasons for this. First, PET scans are easier to interpret when they are corrected for attenuation. A PET camera counts 511 keV photons that are received by its detectors, but this is not the number of photons that are actually emitted. Many photons are attenuated while passing through the body before they reach the camera. In general, the deeper the photons originate within the body, the more tissue they need to pass through, and the more attenuation occurs. Thus the camera sees a greater percentage of the photons that originate near the body surface, less from those that originate deeper within the body. We can create an image from the number of photons actually detected by the PET camera. This is called the nonattenuation corrected image (Fig. 1.1).

   Notice how the surface of the body appears to have more counts than areas deeper in the body. For example, the superficial portion of the liver *(arrow)* appears to have more counts than the deeper portions of the liver in the nonattenuation corrected image (see Fig. 1.1). However, we know that in a normal liver, the number of photons emitted from the liver cells should be about equal. This limits visualization of the deeper structures in the body.

   When we "correct" for attenuation, the FDG images appear the way we are used to seeing them (Fig. 1.2).

   Now the liver appears homogeneous in the attenuation corrected image (see Fig. 1.2). How is this attenuation correction done? The PET/CT camera uses the data from CT photon attenuation as a map to "correct" for attenuation of the photons created by

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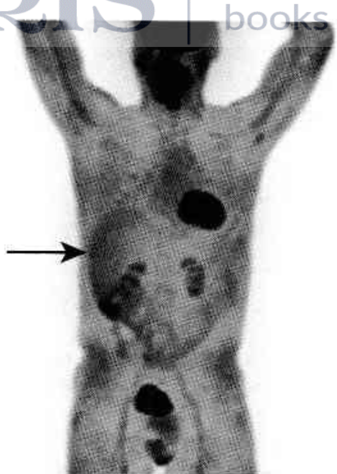

FIG. 1.1 **Nonattenuated corrected maximum intensity projection image from an FDG PET scan.** *Arrow* points at the liver surface, which appears to have more photon counts than the deeper portions of the liver.

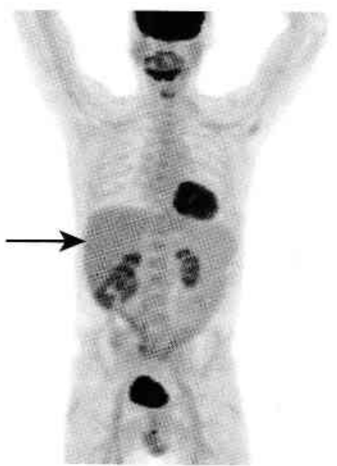

FIG. 1.2 **Attenuated corrected maximum intensity projection image from the same FDG PET scan as Fig. 1.1.** *Arrow* points at the liver surface, which after attenuation correction appears to have the same photon counts as the deeper portions of the liver.

positron annihilation. In general, the attenuation corrected image is much easier to interpret. How does a PET-only camera correct for attenuation? A PET-only camera uses a transmission positron source. Thus both PET-only and PET/CT cameras can effectively correct for attenuation. However, the CT scan takes only seconds to acquire on a PET/CT, but the transmission data may take 30 minutes to acquire

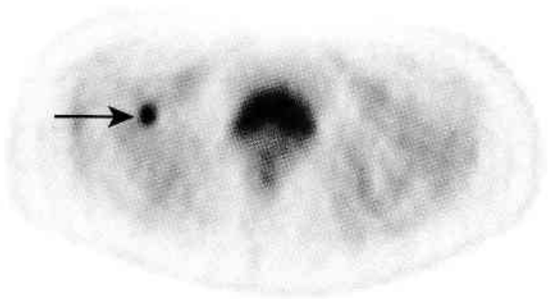

FIG. 1.3 **Axial FDG PET through the pelvis in a patient with breast cancer.** There is an FDG focus in the right pelvis *(arrow)*. The midline FDG avidity is urine in the bladder.

on a PET-only camera. Thus the use of hybrid PET/CT allows much faster patient throughput than a PET-only camera.

Second, the CT component of a PET/CT allows for lesion localization. Sometimes it is difficult to determine where a PET focus is in the body (Fig. 1.3). Fig. 1.3 depicts a patient with breast cancer. There is an FDG focus in the right pelvis. What this FDG focus represents depends on where this focus is. If it is within a bone, then it is suspicious for an osseous metastasis. However, if it is outside the bone in a muscle, then it is probably physiologic muscle and is benign. The ability to fuse the FDG PET and CT images (Fig. 1.4) allows for localization of the FDG focus to the bone, and thus the FDG focus is suspicious for osseous metastasis. This biopsy was proven to be an osseous metastasis.

Third, the CT component of a PET/CT helps with lesion characterization. The corresponding findings on the CT of a PET/CT can help determine what an FDG focus represents (Fig. 1.5). In Fig. 1.5, a patient with lymphoma has an FDG-avid focus in the right inguinal region, which at first glance is suspicious for an FDG-avid lymph node. However, look at the corresponding CT image. The lesion is lower in attenuation than expected for a lymphoma node. The Hounsfield units of this lesion are 0, equal to water. This CT finding would be unusual for a lymphoma node and thus prompts further investigation. The same patient in sagittal projection is shown in Fig. 1.6. On the sagittal PET image, there is again an FDG focus in the right inguinal region; however, on the sagittal CT image, the bladder can be seen to be herniating through an inguinal hernia. The FDG focus in the right inguinal region is due to is a benign bladder hernia, rather than nodal lymphoma. This

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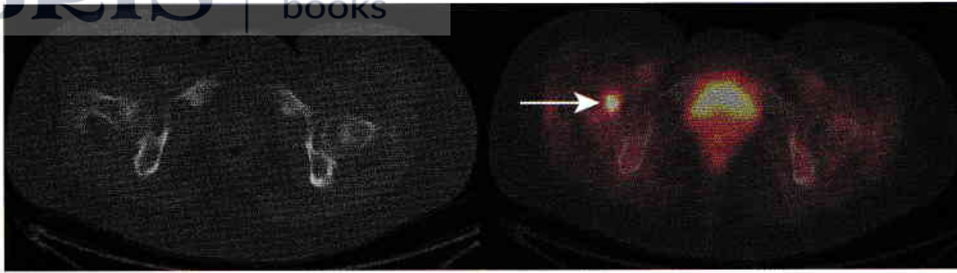

FIG. 1.4 **Axial CT and fused FDG PET/CT that correspond with Fig. 1.3.** The FDG focus in the right pelvis localizes to the right femur *(arrow)* and is suspicious for an osseous metastasis. Biopsy proved this was an osseous metastasis.

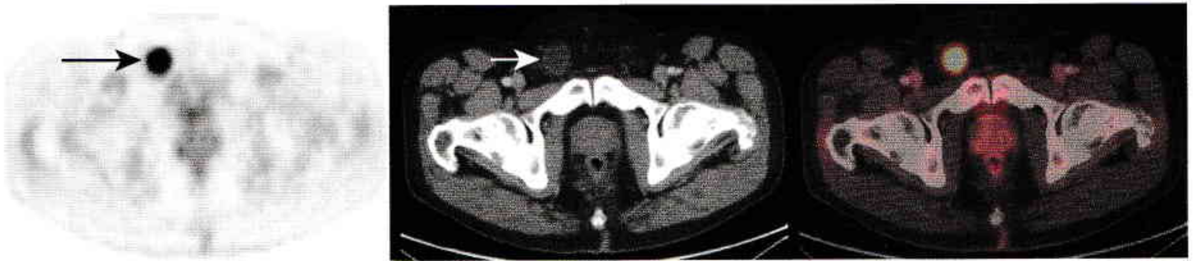

FIG. 1.5 **Axial FDG PET, CT, and fused FDG PET/CT through the pelvis of a patient with lymphoma.** The FDG-avid focus on the PET-only image *(arrow)* is at first glance suspicious for a malignant node. However, on the corresponding CT image, the lesion has attenuation equal to water *(short arrow)*. This is unusual for a lymphoma node and prompts further evaluation.

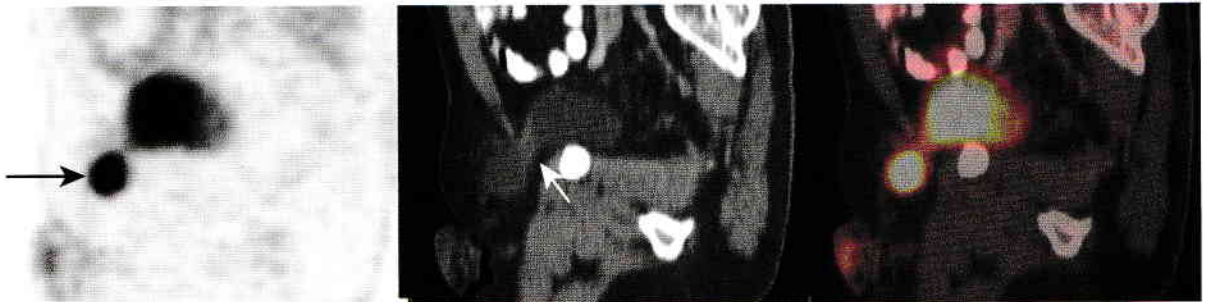

FIG. 1.6 **Sagittal FDG PET, CT, and fused FDG PET/CT through the pelvis of the same patient as Fig. 1.5.** The FDG focus in the right inguinal region is again seen on the PET-only images *(arrow)*. The sagittal CT image demonstrates the herniation of the bladder through an inguinal hernia *(short arrow)*. The CT helps characterize the FDG focus in the right inguinal region as a benign bladder hernia, rather than malignancy.

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explains the Hounsfield units of 0 on CT. The FDG "lesion" is actually only urine within a herniated bladder. The CT component of the PET/CT was instrumental in characterizing the PET finding and preventing misdiagnosis.

Given the advantages for (1) rapid attenuation correction, (2) lesion localization, and (3) lesion characterization, almost all PET scans are performed as hybrid PET/CT scans. Thus this book focuses on hybrid PET/CT.

In summary, the vast majority of PET scans currently performed are hybrid FDG PET/CT for oncology, and thus the majority of this book focuses on these examinations. This content will cover organ system by organ system throughout the body, emphasizing how to integrate FDG PET and CT findings to arrive at the best interpretation of FDG PET/CT studies. My goal is to provide you with an organized, systematic approach to reading oncologic FDG PET/CT.

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CHAPTER 2

FDG PET/CT Performance and Reporting

PERFORMING FDG PET/CT

Patients need to be prepared for 18F-flourodeoxyglucose (FDG) positron emission tomography/computed tomography (PET/CT) in order to optimize the distribution of FDG in the body. Patients should avoid exercise starting the day before the examination in order to prevent muscular FDG uptake. Patients should not consume food or liquids other than unflavored water for at least 4 hours prior to administration of FDG, in order to prevent insulinemia and FDG uptake in muscles and fat. Hydration with a liter of water in the hours before the scan will help dilute excreted FDG in the urine, both reducing patient radiation exposure and artifacts. The patient should be kept warm, starting before FDG administration, in order to prevent FDG-avid brown fat. Blood glucose level is measured before FDG administration, as a glucose level greater than 200 mg/dL may alter FDG biodistribution. FDG is administered intravenously with the patient sitting or lying comfortably, and the patient should remain in this position to minimize muscular uptake. If possible, the patient should remain silent to prevent FDG uptake in vocal musculature, particularly for patients with cancer in the head/neck. The patient should void before being positioned on the PET/CT scanner to remove excreted FDG in the urine. PET/CT imaging usually begins about 60 minutes after FDG administration. The extent of FDG uptake in tissues changes with time; thus it is important to keep the uptake times relatively similar in order to best compare studies. The patient is positioned comfortably on a PET/CT scanner for the examination, which may take 30 to 60 minutes, depending on the field of view and number of minutes per bed position. The typical field of view is the mid-skull to mid-thigh. Additional views of the neck, brain, or extremities may be obtained in selected patients. See Box 2.1 for a list of these maneuvers. Following imaging, CT images are reconstructed and used to create an attenuation map in order to attenuation correct the PET images. CT, nonattenuation corrected PET, and attenuation corrected PET images are produced. The attenuation corrected PET images are usually fused to the CT images to allow evaluation of fused PET/CT images. All images are displayed in multiplanar reconstructions.

QUANTIFYING FDG AVIDITY WITH STANDARDIZED UPTAKE VALUES

FDG avidity is increasingly being quantitated, in order to have numerical values for comparisons. Quantitation of FDG avidity is most commonly performed with standardized uptake values (SUV), a measurement of tracer uptake in a lesion normalized to a distribution volume. There are many different formulas of SUV, depending on how the SUV is normalized (weight, lean body mass [LBM], body surface area), and how the region of interest (ROI) is analyzed (SUVmax, SUVmean, SUVpeak, etc.). Most commonly, SUVmax is reported, which is the SUV normalized for body weight for the most FDG-avid voxel within a ROI. SUV normalized for LBM is called SUL, as is recommended by several organizations. SUL provides less variation in the calculated value than SUV normalized for body weight. However, SUVmax is so highly reproducible and easy to calculate that it is currently the most commonly utilized measure of FDG avidity in clinical practice. SUVmax is calculated as SUVmax = tracer uptake in ROI / (injected activity / patient weight). This provides a number (2, 10, 20, etc.) that conveys a sense of the relative extent of FDG uptake in a lesion.

It is important to remember that calculated SUV values are "semiquantitative." If you perform an FDG PET/CT in the same patient on two consecutive days, you may get slightly different SUV values, despite the lesion truly being the same. This is because the amount of FDG uptake in a lesion is dependent on multiple biologic and technical factors (Box 2.2). For example, higher blood glucose levels may reduce FDG uptake in tumors and a long FDG uptake time (time between FDG injection and image acquisition) often results in increased FDG uptake. To minimize variations in SUV because of these biologic and technical factors, a number of guidelines are suggested for the performance on FDG PET/CT (Box 2.3). These biologic and technical factors often result in a 10% to 20% difference in SUV, even if there is no change in the tumor.

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BOX 2.1
Basic Preparation and Performance of FDG PET/CT

1. Avoid exercise starting the day before the FDG PET/CT.
2. No food or liquids other than water starting at least 4 hours before the FDG PET/CT.
3. Hydration with a liter of water in the hours before FDG administration.
4. Keep patient warm starting before FDG administration.
5. Measure blood glucose level before FDG administration.
6. Administer FDG intravenously while patient sits or lies comfortably and quietly.
7. Patient should void before being placed on PET/CT scanner.
8. Position patient comfortably on scanner for the relatively long image acquisition. Imaging begins about 60 minutes following FDG administration.

BOX 2.2
Some Factors That Influence Standardized Uptake Value

A. Biologic factors
   1. Patient weight
   2. Blood glucose level
   3. Insulin
   4. FDG uptake time
   5. Lesion size (partial volume effects, see Chapter 23)
B. Technical factors
   1. Variability in different scanners
   2. Variation in calibration of scanners
   3. Variability in reconstruction methods
   4. Motion

REPORTING FDG PET/CT EXAMINATIONS

Structured Reports

There are multiple methods to report an oncologic FDG PET/CT examination. The report is often challenging, given the large field of view of oncologic FDG PET/CT scans, often extending from the mid-skull to the mid-thigh, as well as the importance of both FDG PET and CT findings. Presented here is an example of structured PET/CT reporting. The organ system–based outline takes a little while to get used to, but many oncologists and surgeons who

BOX 2.3
Guidelines for Performing FDG PET/CT to Minimize Variability Between Scans

A. Patients should fast a minimum of 4 hours before FDG administration
B. Measured serum glucose should be ≤200 mg/dL.
C. Patients may be on oral hypoglycemic mediations, but not insulin
D. PET scan should be obtained 50–70 minutes after FDG administration, and uptake time on follow-up scans should be within 15 minutes of the baseline scan
E. Scans should be performed on well-calibrated and well-maintained scanners
F. Scans for the same patient should be obtained on the same scanner
G. Scans should be performed with the same administered FDG dose (±20%)
H. Same method of performed and reconstructing the scans should be used

order PET/CT examinations find it useful. If a physician is interested in an analysis of a specific organ, he or she knows exactly where in the report to look. This saves a lot of time for physicians reading the reports. And it ends up saving radiologists a lot of time, too. When dictating a follow-up study, the radiologist can more easily find what he or she needs from the prior report. Again, practitioners not used to a structured report may struggle with it initially, but many who use it come to see its advantages and adapt it for their own purposes. An example of a structured report is demonstrated in Box 2.4.

A few components to notice in the structured FDG PET/CT report:

1. Contrast. Oral and intravenous contrast agents are not required, but often very helpful for interpretation of FDG PET/CT. Most of our FDG PET/CT examinations are performed with low-dose CT component (40–100 mA depending on patient size, 120 kV) with oral contrast (e.g., Omnipaque 300, 30 mL mixed into 1000 mL of water or other sugar-free aqueous diluent) but not intravenous (IV) contrast. A few exceptions:
   a. Pediatric patients (<18 years) are usually not given oral contrast.
   b. When the referring physician orders both an FDG PET/CT and a contrast enhanced CT, the two examinations are combined into one, with a full dose CT scan (variable mA up 400 depending on patient size, 120 kV) performed with both oral

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BOX 2.4
Standard Normal Oncologic FDG PET/CT Structured Report for an Examination From Mid-Skull to Mid-Thighs

BODY FDG PET/CT

CLINICAL STATEMENT: [ ]
RADIOPHARMACEUTICAL: [ ] mCi FDG.
TECHNIQUE: Following intravenous injection of FDG and an approximately [ ] minute uptake period, CT and PET images from the mid-skull to the upper thighs were acquired on the [ ] PET/CT with the patient in the fasted state. [ ] contrast material was administered. Plasma glucose at the time of this test: [ ] mg/dL. The SUV are normalized to patient body weight and indicate the highest activity concentration (SUVmax) in a given disease site.
STUDIES USED FOR CORRELATION: [ ]
FINDINGS:
HEAD/FACE: Physiologic FDG uptake is seen in the visualized regions of the brain, extraocular muscles, large salivary glands, and oropharynx.
NECK: Physiologic FDG uptake is seen in neck muscles.
CHEST: Physiologic FDG avidity is seen in mediastinal blood pool and myocardium.
LUNGS: No abnormal uptake.
PLEURA/PERICARDIUM: No abnormal uptake.
THORACIC NODES: No abnormal uptake.
HEPATOBILIARY: No abnormal uptake. Liver background SUV mean, as a reference for comparing FDG studies, is [ ].
SPLEEN: No abnormal uptake.
PANCREAS: No abnormal uptake.
ADRENAL GLANDS: No abnormal uptake.
KIDNEYS/URETERS/BLADDER: Excreted activity is seen.
ABDOMINOPELVIC NODES: No abnormal uptake.
BOWEL/PERITONEUM/MESENTERY: No abnormal uptake.
PELVIC ORGANS: No abnormal uptake.
BONES/SOFT TISSUES: No abnormal uptake.
OTHER FINDINGS: None.

IMPRESSION:
Since [Date]

SUV, Standardized uptake values.
Used with permission from Memorial Sloan Kettering Cancer Center.

TABLE 2.1
MSKCC Lexicon of Diagnostic Certainty MSKCC 2010

Consistent with	>90%
Suspicious/Probable	~75%
Possible	~50%
Less likely	~25%
Unlikely	<10%

Used with permission of MSKCC, 2010.

and IV contrast (Omnipaque 300 mg iodine/mL, 150 mL delivered via power injector at 2 cc/s).

2. Plasma glucose. Elevated blood glucose may lead to endogenous production of insulin. Insulin may drive FDG into muscles, resulting in suboptimal imaging. To prevent this, we do not administer FDG to a patient until plasma glucose is under 200 mg/dL. There are multiple ways to manage elevated blood glucose levels. Hydration and subcutaneous insulin are possible methods to help lower glucose levels.

3. Liver background. The liver background is used to compare the intensity of liver uptake in the prior study to that of the current study. Small differences are not significant. However, if the current liver background in an SUV is 4, but the prior liver background demonstrates an SUV of 2, this tips us off that the measurement of lesions may not be comparable.

Conveying Diagnostic Certainty

Another reporting issue to consider is how to deal with uncertainty. Sometimes you are not 100% sure what you are looking at! It this scenario I find it useful to use a standard system to describe the confidence of your interpretation. The Memorial Sloan Kettering Cancer Center (MSKCC) Lexicon of Diagnostic Certainty is given in Table 2.1.

For example, Fig. 2.1 demonstrates a tiny FDG avid focus in the right pelvis in a patient with treated cervical cancer. The corresponding CT demonstrates a small soft tissue nodule near the colon. This was new from the prior scan, and there were no other findings of concern. Could this be a metastasis? Yes. Could this be benign? Sure, but less likely. A new FDG-avid soft tissue nodule in the pelvis of a patient with cervical cancer is suspicious for a metastasis. Thus, a reasonable approach to this finding is to dictate in the impression, "FDG-avid small soft tissue nodule in the pelvis of a patient with cervical

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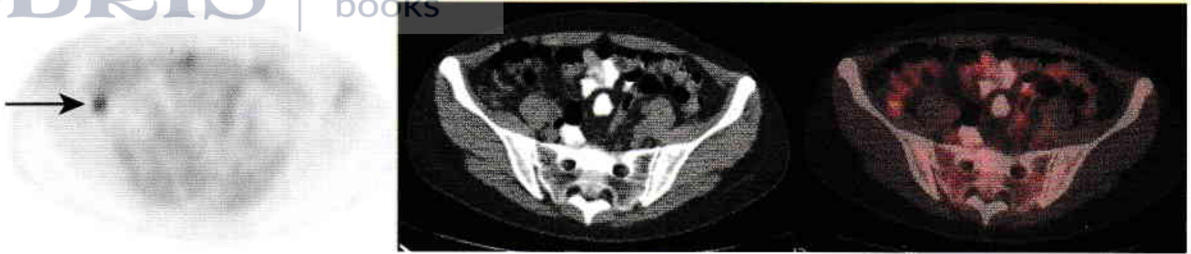

FIG. 2.1 **Axial FDG PET, CT, and Fused FDG PET/CT of a Patient with Treated Cervical Cancer.** The FDG-avid subcentimeter soft tissue nodule in the right pelvis *(arrow)* is new from prior imaging, and thus "suspicious" for metastasis in the MSKCC Lexicon of Diagnostic Certainty. On follow-up this lesion grew and was then biopsy-proven to be a metastasis.

cancer is suspicious for a metastasis." This is probably more helpful than a descriptive sentence such as "FDG-avid small soft tissue nodule in the pelvis," which leaves it up to the person reading the report to determine what it is. Using a system to convey your level of confidence helps the person reading your report, and encourages you to take a stand for what a finding represents. In this case, the follow-up scan demonstrated growth of the nodule and pathology and then confirmed it was a metastasis.

PET Findings Versus CT Findings

A potential pitfall in PET/CT reports is not being clear about whether you are referring to the PET or the CT. A PET/CT report may say, "Unchanged lymph node with increased FDG avidity." This is a contradiction. Is the lymph node unchanged or is there increased FDG avidity? What the radiologist meant to say was, "Unchanged size of a lymph node with increased FDG avidity."

Reference Lesions

There are often many PET and CT findings to describe in an FDG PET/CT report. This can lead to reports that are overly long and less focused in the important issues. One potential way to clarify reports is to use a topic sentence and examples. Compare the following two "thoracic nodes" sections:

THORACIC NODES:
Hypermetabolic left axillary lymph nodes measure up to 1.1 × 1.1 cm at the most superficial location, SUV 7.4. A deeper left axillary node measures 1.7 × 0.9 cm with SUV 5.8. Additional smaller hypermetabolic left axillary nodes are present. Hypermetabolic left supraclavicular lymph node measuring 1.8 × 1.2 cm, SUV 6.8. Enhancing 0.9 × 0.9 cm left supraclavicular node and adjacent smaller left supraclavicular nodes measuring up to 0.7 × 0.6 cm; however, diffuse hypermetabolism in the supraclavicular and infraclavicular regions related to brown fat limits evaluation of FDG uptake in the supraclavicular lymph nodes.

Versus

THORACIC NODES:
FDG avid axillary and supraclavicular nodal metastases, seen among brown fat. Reference Lesions:

1. Left axillary node, 1.1 × 1.1 cm, SUV 7.4.
2. Left supraclavicular node, 1.8 × 1.2 cm, SUV 6.8.

Which example is easier to read and understand? The topic sentence with "reference lesions" (or "examples," or whatever you want to call them) is a technique that helps de-clutter and clarify reports. Many physicians have found this "reference lesion" system to be faster and more clear than the free text example above.

SUGGESTED READINGS

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CHAPTER 3

Skeleton on FDG PET/CT

When approaching interpretation of osseous lesions on 18F-fluorodeoxyglucose positron emission topography/computed tomography (FDG PET/CT), it may be useful to use a 2 × 2 box divided into quadrants based on presence or absence of FDG avidity and malignant versus benign (Fig. 3.1). Malignancy is often FDG avid, and thus FDG PET helps to identify malignancy that is otherwise difficult to appreciate. However, it is important to remember that not all malignancy is FDG avid, and not everything that is FDG avid is malignant. The combination of the FDG PET and CT findings often allows us to properly identify a finding as benign or malignant.

FDG-AVID CANCER

Metastases

The upper right-hand corner of the 2 × 2 box is where FDG PET provides tremendous value. FDG PET often provides superior evaluation of osseous metastases than anatomic imaging such as CT and even magnetic resonance (MR). CT requires substantial alterations in the structure of bone before the lytic or sclerotic changes allow for identification of osseous malignancy. Thus FDG PET has higher sensitivity for detection of osseous malignancy than CT in most cases.

Fig. 3.2 demonstrates a patient with invasive ductal breast cancer. The patient was initially stage IIIB (locally advanced breast cancer [LABC]). LABC would be treated with neoadjuvant chemotherapy and surgery. FDG PET/CT demonstrates unsuspected distant metastases in approximately 30% of locally advanced ductal breast cancer. The identification of these previously unsuspected distant metastases increases the patient's stage to IV (metastatic disease) and changes the treatment strategy from neoadjuvant chemotherapy and surgery to palliative systemic therapy. An example of this is seen in Fig. 3.2. FDG PET/CT identified a previously unsuspected osseous metastasis, dramatically altering this patient's course of treatment. There was no definite corresponding abnormality on CT, thus the FDG PET demonstrated CT occult malignancy. Some may suggest that the osseous lesion could have been detected by 99m-technetium methylene diphosphonate (MDP) bone scan; however, in this case a bone scan had been recently performed and failed to identify the osseous metastasis. This is a demonstration of how FDG PET/CT may replace the use of CT with bone scan for systemic staging of patients with breast cancer.

It is not uncommon for FDG PET to identify CT occult osseous metastases. Thus round foci of FDG avidity within a bone, without a CT correlate, should be considered suspicious for osseous metastases until proven otherwise (Fig. 3.3). Even small FDG-avid foci within the bone without CT correlate are significant (Fig. 3.4).

In addition to early detection of osseous metastases, FDG PET greatly adds to the follow-up of osseous metastases. It may be very difficult to determine whether osseous disease is increasing, decreasing, or unchanged on anatomic imaging, whereas FDG PET more accurately demonstrates the extent of active malignancy (Fig. 3.5).

Lymphoma

Similar as for osseous metastases, FDG PET often provides greater sensitivity for detection of osseous lymphoma than does anatomic imaging. After the diagnosis of lymphoma, common staging studies include FDG PET/CT and bone marrow biopsy. Bone marrow biopsy is usually performed in the posterior pelvis and may detect osseous lymphomatous involvement in the absence of focal FDG avidity. However, bone marrow biopsy samples only one specific osseous site, and thus body imaging with FDG PET may demonstrate foci suspicious for lymphomatous involvement in the absence of positive bone marrow biopsy. In this case, FDG PET/CT may provide localization for a potential biopsy site to pathologically document osseous lymphoma. Some studies have suggested that focal osseous FDG avidity that is suspicious for osseous lymphoma may be taken as evidence of osseous lymphoma without pathologic proof. After diagnosis, FDG PET/CT provides valuable information about response to therapy in osseous lymphoma, similar to other sites of lymphomatous involvement. The Lugano Criteria state that (for initially

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		Malignant	Benign
FDG avidity	+	FDG-avid cancer	FDG avid but not cancer
	−	Not FDG avid but cancer	Not FDG avid and not cancer

FIG. 3.1 This 2 × 2 box defines categories of osseous lesions on FDG PET/CT by FDG avidity and malignant/benign.

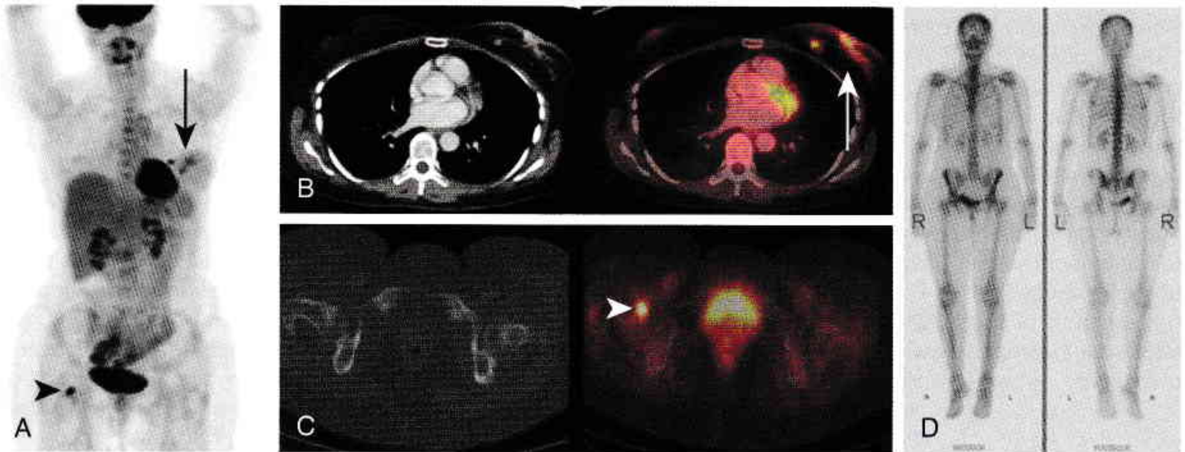

FIG. 3.2 **FDG PET Identifies a Previously Unsuspected Osseous Metastasis in a Patient with Newly Diagnosed Locally Advanced Invasive Ductal Breast Cancer.** (A) FDG PET maximum intensity projection demonstrates FDG avidity overlying the left chest *(arrow)* and a focus in the right lower pelvis *(arrowhead)*. (B) Axial CT and fused FDG PET/CT images through the chest demonstrate FDG avidity and correspond with multifocal breast opacities on CT, representing the patient's primary locally advanced breast malignancy *(arrow)*. (C) Axial CT and fused PET/CT images demonstrate the FDG focus in the right pelvis corresponds to the right femoral head *(arrowhead)*, without CT correlate. Biopsy of this lesion demonstrated an osseous metastasis and increased this patient's stage to IV (metastatic disease). (D) Anterior and posterior whole-body planar MDP bone scan images failed to demonstrate the osseous metastasis.

FDG-avid lymphoma) posttreatment reduction of FDG avidity to less than liver background represents a complete response to treatment, whereas residual FDG avidity greater than liver background is suspicious for residual active lymphoma.

Multiple Myeloma

Traditional staging of multiple myeloma was performed with skeletal survey radiographs; however, the use of FDG PET/CT and whole-body MR is increasing. The 2014 International Myeloma Working Group Consensus now includes FDG PET/CT criteria for diagnosis of multiple myeloma. Interestingly, it is not the presence of FDG-avid osseous lesions, but rather the presence of osteolytic osseous lesions on the CT component that is used to make the diagnosis of myeloma. Osseous FDG avidity needs to correlate with a lytic lesion on CT, signal abnormality on MR, or biopsy-proven myeloma to be used for myeloma diagnosis. At diagnosis, multiple myeloma demonstrates a range of FDG avidity, extending from not appreciably avid to markedly FDG avid. For myeloma with appreciable FDG avidity at diagnosis, follow-up FDG PET/CT can be used to demonstrate treatment response. Changes in FDG avidity following treatment on FDG PET usually occur more rapidly than do changes apparent on CT or MR anatomic imaging.

Primary Osseous Sarcomas

FDG PET has little value in the diagnosis of primary osseous sarcomas, such as osteosarcoma or Ewing sarcoma. These sarcomas are far better diagnosed by

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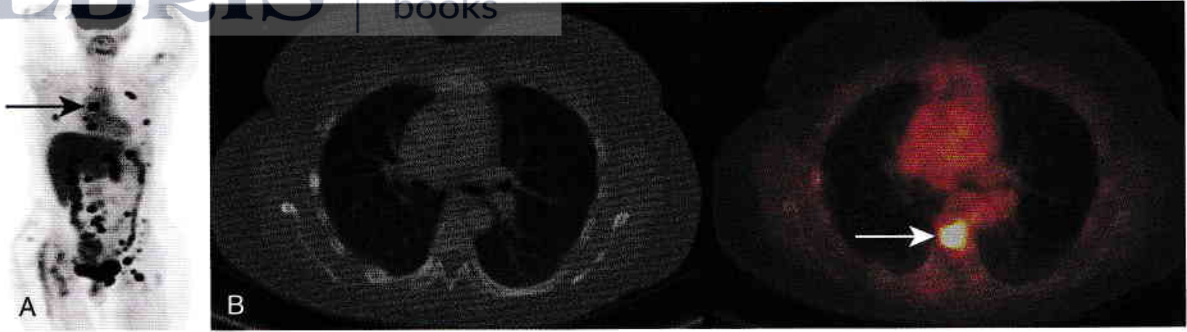

FIG. 3.3 FDG PET Identifies Previously Unsuspected Widespread Osseous Metastases in a Patient with Ductal Breast Cancer. (A) FDG PET maximum intensity projection (MIP) demonstrates multiple FDG-avid foci, for example in the mid-thorax *(arrow)*. (B) Axial CT and fused FDG PET/CT images demonstrate the focus in the mid-thorax localizes to a vertebral body *(arrow)*, without CT correlate. Similar findings were found for the other FDG-avid foci. These represent previously unsuspected widespread osseous metastatic disease.

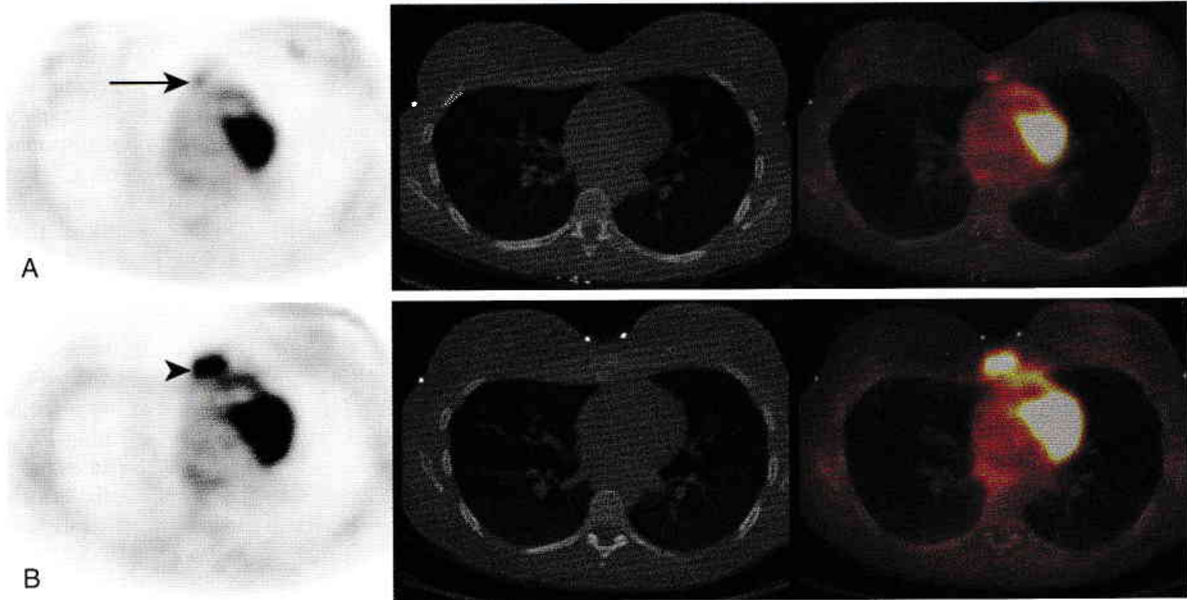

FIG. 3.4 Small FDG-avid Osseous Focus Is an Early Metastasis. (A) Axial FDG PET, axial CT, and fused FDG PET images demonstrate a small focus of FDG avidity which localizes to the sternum *(arrow)*, without CT correlate. This was called suspicious for osseous metastasis, although this was the only suspicious finding and there was no change in patient management. (B) Axial FDG PET, axial CT, and fused FDG PET images 6 months later demonstrate an increased FDG-avid osseous metastasis *(arrowhead)* now with a lytic correlate on CT.

radiograph, CT, or MR imaging. FDG PET/CT could be used for systemic staging of osseous sarcomas because sites of osseous metastases may be detected by whole-body imaging. Lung metastases, a common site of metastatic disease from primary sarcomas, are probably better evaluated by dedicated chest CT imaging than by FDG PET/CT because dedicated chest CT imaging can be performed with breath-hold, which increases the ability to detect small pulmonary lesions. The CT component of FDG PET/CT is typically performed during