FDG PET/CT: Artifacts and Pitfalls

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After participating in this educational activity, the diagnostic radiologist should be better able to identify and prevent common artifacts and pitfalls observed on FDG PET/CT examinations.

Introduction

The use of PET/CT has been increasing worldwide because of its increased sensitivity and specificity in cancer imaging. Functional information obtained during FDG PET examination can be localized more precisely to anatomic correlates on the CT examination. Furthermore, the use of the CT examination for attenuation correction of PET data has decreased scan times significantly. However, there are potential pitfalls of PET/CT that may result in false-positive or false-negative examinations. Artifacts also may be generated with the fusion of PET/CT in addition to the artifacts found in each of the separate modalities. It is essential for radiologists interpreting PET/CT to be aware of these artifacts and pitfalls and techniques to mitigate them.

F-18 FDG

Multiple radiotracers may be used for PET/CT including FDG and F18-sodium fluoride. The most commonly used radiotracer is FDG, a glucose analogue used to assess tissue metabolism. FDG is a positron emitter with a half-life of approximately 110 minutes. The positrons collide with electrons resulting in an annihilation reaction that produces two 511-KeV photons 180 degrees from each other. Counts detected 180 degrees from each other within a narrow time frame are recorded (coincidence imaging). A maximum intensity projection (MIP) image is then constructed from the data. CT also is performed, and the data is used to provide...
PET/CT

Patient preparation is critical for optimal PET data. The goal is to decrease activity in normal tissue while maintaining activity in the target tissue. Patients should fast for at least 4 hours before FDG IV injection to decrease blood glucose and insulin levels to basal levels. A high-protein, low-carbohydrate meal before the PET/CT examination also may be helpful. Blood glucose should be checked before FDG injection. If the blood glucose level is greater than 200 mg/dL, the examination should be rescheduled. Current recommendations are to avoid the use of insulin before the FDG PET examination due to its impact on the biodistribution of the radiotracer, although some institutions have had selective success using it in patients with diabetes. Insulin causes cells to take up FDG and glucose and results in diffuse muscle uptake.

After FDG injection, the patient should wait in a quiet, warm, and dimly lit room to help minimize uptake of FDG by muscles and benign metabolically active brown fat. Imaging is performed after an uptake period of approximately 60 to 90 minutes, with subsequent examinations performed at the same time interval from injection to ensure image standardization. The patient should be positioned on the table according to desired field of view (FOV) with arms generally up to reduce attenuation artifact. However, the arms may be placed down at the patient’s side if the primary area of concern is in the head or neck, or if it is necessary to include the arms in the FOV as is typical for patients with melanoma or an upper extremity sarcoma. It is important for the patient to remain still and silent during image acquisition, and the patient should be instructed to maintain quiet respiration during the examination to optimize alignment of PET and CT data in the lungs and upper abdomen.

Normal physiologic activity is seen throughout the body (Figure 1). Activity in the head includes the cerebral cortex, basal ganglia, thalamus, and cerebellum. Although decreased in the fasting state, physiologic activity also is present in the myocardium. Activity is filtered out into the renal collecting system and accumulates in the bladder.1 Gastrointestinal activity is variable but can be seen within the stomach, small bowel, or colon.2 Skeletal muscles may show greater accumulation of radiotracer after exercise, which can reduce the conspicuity of soft tissue lesions and decrease the amount of FDG available for uptake by malignant lesions (Figure 2).3

Artifacts

An artifact is a substance or structure present in an image that was not present originally in the object being imaged. Artifacts in PET/CT can be organized into three categories: radiotracer related, patient related, or instrument related (Table 1).

Radiotracer-related artifacts typically involve an error during the radiotracer injection process. The first type is the hot-clot artifact. Blood may coagulate when it is aspirated into the syringe with the radiotracer, resulting in a radioactive microembolus that is then injected into the patient, creating a pulmonary “hot clot.” This artifact may be diagnosed by identifying a small intense focus of activity in the lungs that has no anatomic correlate on CT (Figure 3). To prevent this artifact from occurring, it is important to have secure IV access, to prevent paravenous injection, and to avoid aspiration of blood into the syringe containing radiotracer or injection of radiotracer through a line that has not been flushed.

Dose extravasation is another injection-related error, and it can result in up to three types of artifact. The first is intense hypermetabolic activity at the site of injection that should not be confused for a malignant soft tissue lesion (Figure 4). Second, the extravasated dose is cleared by the lymphatic system and accumulates in the bladder. 1 Gastrointestinal activity is variable but can be seen within the stomach, small bowel, or colon.2 Skeletal muscles may show greater accumulation of radiotracer after exercise, which can reduce the conspicuity of soft tissue lesions and decrease the amount of FDG available for uptake by malignant lesions (Figure 2).3

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system and follows a normal drainage pattern, which can result in FDG avid axillary lymph nodes. This may give the false appearance of lymphatic spread of disease.\(^4\) When this occurs, it is essential that one review the CT images for concordant anatomic evidence of nodal pathology and consider the abnormality in the context of the patient’s underlying disease process. For example, in the setting of renal cell carcinoma, it would be unlikely that anatomically normal appearing FDG avid axillary lymph nodes are the result of metastases, and one can be confident that they are related to the ipsilateral soft tissue extravasation. However, in the setting of lymphoma, definitive differentiation may not be possible, and the examination should be repeated. The third effect of dose extravasation is its effect on the measured standardized uptake values (SUVs). Because a large amount of the FDG accumulates in the injection site rather than being distributed throughout the body, this will affect the calculated SUVs measured throughout the body, at sites of both normal and pathologic uptake. This is because SUV calculations are based upon an assumed normal distribution of FDG. When

**Figure 1.** MIP image from FDG PET/CT examination shows normal biodistribution, which includes intense uptake in the brain, heart, and kidneys; and mild-to-moderate uptake in the liver, spleen, bone marrow, and gastrointestinal tract. Benign muscle uptake is present at the gastroesophageal sphincter (arrow). Intense activity is seen in the excreted urine of the renal pelves and right ureter (arrowheads).

an abnormal amount of radiotracer remains at the site of injection instead of spreading throughout the body, it will spuriously decrease the calculated SUVs and, therefore, potentially result in a false-negative assessment.

**Figure 2.** A: MIP image from FDG PET/CT examination in a young man after therapy for lymphoma shows extensive increased FDG uptake throughout multiple major muscle groups secondary to strenuous exercise leading up to the day of examination. No active focus of lymphoma is visible. B: Repeat examination shows resolution of abnormal muscle uptake, normal biodistribution of FDG, and newly visible mild metabolic activity in two right axillary lymph nodes representing residual lymphoma (arrow).
Table 1. PET/CT Artifacts

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<thead>
<tr>
<th>Artifact</th>
<th>Diagnosis</th>
<th>Prevention</th>
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<tbody>
<tr>
<td>Patient related</td>
<td>Misregistration</td>
<td>PET data is superimposed incorrectly on CT images</td>
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<tr>
<td>Large size patient</td>
<td>Degraded image quality</td>
<td></td>
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<tr>
<td>Beam hardening</td>
<td>Abnormal attenuation traversing bands traversing body</td>
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<tr>
<td>Radiotracer related</td>
<td>Hot-clot</td>
<td>Small foci of activity, microemboli, in the lungs without anatomic correlate</td>
</tr>
<tr>
<td></td>
<td>Dose extravasation</td>
<td>Intense activity at injection site. May also follow lymphatics</td>
</tr>
<tr>
<td>Scatter</td>
<td>Intense activity in bladder with absent adjacent activity</td>
<td></td>
</tr>
<tr>
<td>Instrument related</td>
<td>Attenuation correction</td>
<td>Intense activity on attenuation-corrected PET images without corresponding activity on NAC images</td>
</tr>
<tr>
<td>Truncation</td>
<td>Peripheral activity on PET images with region of interest outside the FOV on CT</td>
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Scatter artifact from accumulation of intense radiotracer uptake also can be seen, most commonly in the bladder, given the physiologic excretion of radiotracer in the urine. Not only can the intense uptake make it difficult to assess the metabolic activity in immediately adjacent structures such as the prostate, cervix, and adnexa, but the attenuation artifact related to the intense uptake also results in a band of absent activity extending into adjacent structures. Hydration, and voiding immediately before scanning, can help to prevent or minimize this artifact.

Patient-related artifacts also are common in PET/CT. Contrary to popular belief, the CT and PET data sets are not acquired simultaneously but instead sequentially on the same scanner. Therefore, although the PET data set is acquired immediately after the CT scan, with the patient remaining on the same scanner table and in the same position, patient motion may still occur, resulting in misregistration of PET data with CT images. This misregistration is encountered most commonly in the region of the head and neck because the CT scan is acquired head-to-toe, and the PET image is next acquired in reverse direction, toe-to-head. This technique results in several minutes passing between the head and neck being scanned by CT and its corresponding PET. Therefore, despite the use of fixation devices and instructing the patient to remain still, it is not uncommon for tilting or turning of the head to occur during image acquisition, which can cause normal sites to appear hypermetabolic and vice versa. When this misregistration occurs, close attention to the CT scan for anatomic evidence of pathology can be helpful. In addition, it is important to review the non-attenuation-corrected (NAC) PET data. The NAC PET data is the raw PET data before it undergoes attenuation correction using the CT data. Although the NAC PET data is not an optimal representation of the distribution of FDG throughout the body, it is not susceptible to attenuation or misregistration artifacts, and, therefore, it may help confirm or exclude the presence of FDG avid disease (discussed further in instrument-related artifacts).

In other instances, patient motion artifact may be subtle, as seen because of differences in lung volumes between PET and CT acquisitions. The typical presentation is a curvilinear hypermetabolic focus in the lung bases without an anatomic correlate on CT. Coaching the patient to breathe normal, shallow breaths rather than deeper, more variable breaths, decreases the severity of this artifact. Other techniques used to decrease respiratory misregistration include use of abdominal compression devices and performing CT during end-expiration to approximate the PET data more closely.

Patient size also affects image quality; larger patients require greater dose or longer scan time to detect an adequate number of photons and thus preserve image quality. When these parameters are not adjusted, image quality is degraded. Time-of-flight reconstruction also can be performed to improve image quality by more accurately localizing the photons, point of origin in the body.

Beam-hardening artifact is another common patient-related artifact in PET/CT. Like traditional CT, the artifact appears as multiple linear bands of abnormal attenuation traversing a body part adjacent to high-attenuation objects, such as metal or bone. The easiest way to prevent this artifact is to perform the scan with arms up or down, depending on clinical concerns.

The last category of artifacts in PET/CT is instrument-related artifacts. These artifacts are the result of the scanner hardware or postprocessing. The most common of these artifacts is attenuation correction artifact. The purpose of the CT portion of PET/CT is twofold. One is for anatomic correlation of functional data. The second is that the CT scan also is used for attenuation correction resulting in up to 40% reduction of imaging time compared with when a second PET source, such as Cesium, is used to map for attenuation. Unfortunately, when high-density material is present in the patient (such as concentrated IV or oral contrast-medium, metallic hardware, or methylmethacrylate), the PET data is overcorrected because the CT-based attenuation correction model becomes
Truncation is another instrument-related artifact. This artifact occurs because the CT FOV is smaller than the PET FOV secondary to hardware limitations. As a result, at the periphery of the images, there will be metabolic data without corresponding CT data to provide attenuation correction. This typically occurs in large patients or affects the upper extremities when the extremities are placed at the patient’s side, as is typical for imaging of melanoma or head and neck cancer. The amount of FDG uptake in the area of PET and CT FOV mismatch thus will be biased, a discrepancy that may result in over- and underestimation of the distribution of FDG (Figure 6). To minimize this artifact, patients should be centered in the FOV and imaged with arms positioned above the head whenever possible. In addition, new scanners have been manufactured with larger CT FOVs, making it easier to avoid truncation.

**Pitfalls**

A pitfall is defined as any trap or danger for the unwary. In addition to artifacts, radiologists also need to be aware of pitfalls including normal variants, physiologic uptake, benign processes that may mimic malignant disease, and non-FDG inaccurate at very high Hounsfield units (Figure 5). This results in the false representation of hypermetabolic activity at the area of high density on CT on the attenuation-corrected PET images. To avoid this pitfall, one must be aware of the potential for attenuation correction artifact and, when suspected, be sure to review the NAC PET images. Because the NAC PET images represent the raw unprocessed data, they are devoid of attenuation correction-related artifacts. Therefore, the spurious FDG activity seen on the standard attenuation-corrected data set used for diagnostic interpretive purposes will not be present, allowing one to avoid overdiagnosing pathology.

Figure 3. MIP image (A), axial fused image (B), and CT scan (C) from FDG PET/CT show an intense focus of metabolic activity in the right middle lobe without anatomic correlate (dashed circle), consistent with an FDG microembolus.

Figure 4. MIP image (A) and axial fused image (B) from FDG PET/CT show a large area of abnormal FDG avidity in the dorsum of the left hand and wrist. CT scan (not shown) showed no anatomic correlate. Review of radiotracer injection with the patient and technologist confirmed partial dose extravasation.

Figure 5. MIP image from FDG PET/CT show a large area of abnormal FDG avidity in the dorsum of the left hand and wrist. CT scan (not shown) showed no anatomic correlate. Review of radiotracer injection with the patient and technologist confirmed partial dose extravasation.
avid malignancies. Muscles accumulate glucose during and after activity and thus can accumulate excessive amounts of FDG. Therefore, patients are advised to not engage in vigorous physical activity for 24 to 48 hours before FDG PET/CT. In addition, skeletal muscle increases its uptake of FDG during periods of hyperglycemia or when insulin has been administered recently, due to upregulation of GLUT4 transporters. Blood glucose is checked before radiotracer injection, and insulin is withheld before the examination to prevent this potential pitfall. In both cases, muscle uptake is typically linear or diffuse, symmetric, and associated with normal appearance on CT. Symmetric uptake of FDG in skeletal muscles, specifically the psoas and rectus abdominis muscles, also has been documented in patients with Graves’ disease. However, muscle uptake also may be asymmetric due to prior surgery or neoplasm.

Brown adipose tissue (BAT), also known as brown fat, may accumulate FDG and result in a false-positive examination. Related to nonshivering thermogenesis, BAT locations commonly include the supraclavicular, infraclavicular, neck, mediastinum, axilla, perinephric, and intercostal spaces. It is generally bilateral, with asymmetry sometimes seen in the mediastinum, and always corresponds to normal-appearing fat on the corresponding CT examination (Figure 7). Avoiding cold exposure on the days before the examination and keeping the patient warm between radiotracer injection and imaging

Figure 5. Coronal, attenuation-corrected PET image (A) and coronal CT image (B) from an FDG PET/CT examination show intense FDG avidity corresponding to methylmethacrylate vertebral body augmentation (arrows). Coronal NAC PET image (C) reveals no corresponding FDG avidity (arrow).

Figure 6. MIP image (A) and axial PET image (B) of FDG PET/CT examination obtained for staging of malignant right upper lobe nodule demonstrate intense FDG avidity involving the lateral aspect of the patient’s left forearm (arrow). Fused data (C) demonstrates that the FDG avidity corresponds to a site of mismatch between the CT and larger PET FOV, resulting in truncation artifact.
are the most effective ways to prevent FDG accumulation in brown fat.

In addition to these physiologic processes, some benign neoplasms such as eosinophilic granuloma and neurogenic tumors, and infection and inflammation, may be FDG avid and thus mimic a malignant process. Examples of inflammatory conditions include arthritis, arthroplasty, fractures, avascular necrosis, sarcoidosis, and plantar fasciitis. Red marrow FDG avidity also has been documented, most commonly due to anemia, and it may appear symmetric or asymmetric. Other potential causes of increased red marrow FDG avidity include young patients (<25 years), neoplasia, and use of substances that stimulate marrow such as granulocyte colony-stimulating factor (G-CSF) and erythropoietin. Osteonecrosis is a known complication of the selective tyrosine kinase inhibitor imatinib, which is used to treat chronic myelogenous leukemia and gastrointestinal stromal tumors, and it is associated with FDG avidity resulting in a false-positive examination.

False-negative examinations may occur as well. Neoplasms smaller than 8 mm that are not intensely avid may not appear avid on PET/CT because of resolution limitations of current PET detectors. Also, several types of tumors typically are not FDG avid, such as low-grade chondrosarcoma, well-differentiated prostate carcinoma, and carcinoid (Table 2).

Conclusion
PET/CT combines anatomic and physiologic information that improves detection and assessment of malignant neoplastic disease. The interpreting radiologist must recognize artifacts and take appropriate measures to prevent them. PET/CT examinations need to be interpreted in the appropriate clinical context and in correlation with other diagnostic studies. This CME activity emphasizes that recognizing normal physiologic and benign activity, and differentiating it from malignancy, is essential to avoiding potential diagnostic pitfalls.

Table 2. Common Pitfalls of FDG PET/CT Examinations

<table>
<thead>
<tr>
<th>False positive</th>
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<tr>
<td>Hyperglycemia or insulin related</td>
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<tr>
<td>Brown fat</td>
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<tr>
<td>Muscle uptake</td>
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<tr>
<td>Benign neoplasms</td>
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<tr>
<td>Neurofibroma</td>
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<tr>
<td>Pigmented villonodular synovitis</td>
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<td>Schwannoma</td>
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<tr>
<td>Red marrow</td>
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<td>Anemia (reconversion)</td>
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<tr>
<td>G-CSF (stimulation)</td>
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<tr>
<td>Benign lesions</td>
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<tr>
<td>Eosinophilic granuloma</td>
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<tr>
<td>Fibrous dysplasia</td>
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<tr>
<td>Giant cell tumor</td>
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<tr>
<td>Nonossifying fibroma</td>
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<tr>
<td>Paget disease of bone</td>
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<tr>
<td>Inflammation</td>
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<tr>
<td>Arthritis</td>
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<tr>
<td>Fractures</td>
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<td>Avascular necrosis</td>
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<tr>
<td>Imatinib-related osteonecrosis</td>
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<tr>
<td>Arthroplasty</td>
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<tr>
<td>Sarcomatosis</td>
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<tr>
<td>False negative</td>
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<tr>
<td>Soft tissue neoplasms</td>
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<tr>
<td>Synovial sarcoma</td>
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<tr>
<td>Well-differentiated liposarcoma</td>
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<tr>
<td>Malignant myxoid tumors</td>
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<tr>
<td>Neuroendocrine tumors</td>
</tr>
<tr>
<td>Renal cell carcinoma</td>
</tr>
<tr>
<td>MALT lymphoma</td>
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<tr>
<td>T-cell lymphoma</td>
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<tr>
<td>Mucinous carcinoma of colon</td>
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<tr>
<td>Transitional cell carcinoma</td>
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<tr>
<td>Clear cell ovarian cancer</td>
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<tr>
<td>Carcinoid</td>
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<tr>
<td>Well-differentiated prostate cancer</td>
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<tr>
<td>Bone neoplasms</td>
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<tr>
<td>Low-grade chondrosarcoma</td>
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<td>Sclerotic metastasis</td>
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MALT, mucosa-associated lymphoid tissue.

References
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1. Which one of the following artifacts is the result of aspiration of blood into the syringe containing radiotracer for an FDG PET/CT examination?
   A. Misregistration
   B. Pulmonary hot-clot sign
   C. Truncation
   D. Attenuation correction
   E. Scatter

2. A truncation artifact on an FDG PET/CT examination can be prevented by
   A. coaching the patient on shallow breathing
   B. centering the patient in the FOV with arms above the head
   C. using an abdominal compression device
   D. inserting a Foley catheter in the bladder
   E. rapid IV injection of radiotracer

3. Which one of the following conditions is least likely to be FDG avid in an FDG PET/CT examination?
   A. Pigmented villonodular synovitis
   B. Sclerotic metastasis
   C. Sarcoidosis
   D. Paget disease of bone
   E. Imatinib-related osteonecrosis

4. Which of the following conditions is/are FDG avid on an FDG PET/CT examination?
   A. Neurofibroma
   B. Schwannoma
   C. Arthroplasty
   D. Healing fracture
   E. All of the above

5. Which of the following statements regarding patient preparation for an FDG PET/CT examination is true?
   A. The PET/CT room should be cold for ideal uptake of the radiotracer.
   B. Blood glucose levels have no impact on the examination.
   C. Insulin should be given to diabetic patients before the examination.
   D. Patients should not engage in vigorous exercise before the examination.
   E. Morphine is commonly given before the examination to decrease brown fat uptake of the radiotracer.

6. Which one of the following statements concerning PET/CT acquisition is true?
   A. PET and CT data are acquired simultaneously.
   B. PET images are acquired approximately 120 minutes after radiotracer injection.
   C. Patients are encouraged to talk during PET data acquisition.
   D. Radiotracer must be injected through a central line.
   E. CT data is used for attenuation correction of the PET examination.

7. All of the following bone lesions are FDG avid, except
   A. giant cell tumor
   B. low-grade chondrosarcoma
   C. nonossifying fibroma
   D. fibrous dysplasia
   E. Paget disease of bone

8. The scatter artifact in FDG PET/CT examinations is most likely due to
   A. radiotracer intense activity at the injection site
   B. increased physical activity just before the examination
   C. accumulation of intense radiotracer in the bladder
   D. hyperglycemia
   E. patient motion during the examination

9. Which one of the following artifacts on an FDG PET/CT examination is related to abnormal patient respiration during the examination?
   A. Scatter
   B. Truncation
   C. Beam hardening
   D. Misregistration
   E. Pulmonary hot-clot

10. Which one of the following artifacts on an FDG PET/CT examination is instrument related?
    A. Truncation
    B. Beam hardening
    C. Misregistration
    D. Scatter
    E. Dose extravasation