PET/CT Imaging Artifacts*

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The purpose of this paper is to introduce the principles of PET/CT imaging and describe the artifacts associated with it. PET/CT is a new imaging modality that integrates functional (PET) and structural (CT) information into a single scanning session, allowing excellent fusion of the PET and CT images and thus improving lesion localization and interpretation accuracy. Moreover, the CT data can also be used for attenuation correction, ultimately leading to high patient throughput. These combined advantages have rendered PET/CT a preferred imaging modality over dedicated PET. Although PET/CT imaging offers many advantages, this dual-modality imaging also poses some challenges. CT-based attenuation correction can induce artifacts and quantitative errors that can affect the PET emission images. For instance, the use of contrast medium and the presence of metallic implants can be associated with focal radiotracer uptake. Furthermore, the patient's breathing can introduce mismatches between the CT attenuation map and the PET emission data, and the discrepancy between the CT and PET fields of view can lead to truncation artifacts. After reading this article, the technologist should be able to describe the principles of PET/CT imaging, identify at least 3 types of image artifacts, and describe the differences between PET/CT artifacts of different causes: metallic implants, respiratory motion, contrast medium, and truncation.

Key Words: PET/CT; attenuation correction; artifacts

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In the last 2 years, PET imaging in oncology has been migrating from the use of dedicated PET scanners to the use of PET/CT tomographs. According to a recent market study, sales of PET/CT scanners have surpassed those of dedicated PET scanners by 65% since 2003, and sales of PET/CT scanners are anticipated to grow by more than 95% over the next few years (*1*). At this rate, it is not surprising that PET/CT imaging will soon replace dedicated PET imaging. This shift to dual-modality imaging is primarily due to the advantages that PET/CT offers over dedicated PET. One of these advantages is the ability to integrate PET and CT imaging into a single scanning session, thus allowing excellent fusion of the acquired data. This capability has been shown to increase the diagnostic accuracy of PET scans from 91% to 98% (*2*), significantly affecting diagnosis and staging of malignant disease, as well as identification and localization of metastases (*2–4*). In addition, CT-based attenuation correction in PET/CT imaging is more rapid than the traditional transmission attenuation correction, thus reducing the overall whole-body PET scanning time by 30%–40% and allowing higher patient throughput with less patient discomfort. However, the use of the CT scan for attenuation correction has the drawback of producing artifacts on the resulting PET images. In this article, we will describe the basics of PET/CT scanner design, data acquisition, and image artifacts.

SCANNER DESIGN AND CONFIGURATION

In a PET/CT scanner, the PET and CT tomographs are housed in a single gantry. The CT tomograph is usually in the front of the gantry, and the PET tomograph in the back (Fig. 1). State-of-the-art PET/CT scanners usually have a bore size of 70 cm and an axial length of 100 cm. This large bore has 2 purposes; it allows the use of immobilization devices, such as body molds and head casts, and accommodates large patients. PET/CT scanners can be used either as a dedicated PET scanner or as a dedicated CT scanner (*3*). The CT scanner can be dual or multislice, with axial or helical acquisition modes and different rotation speeds, and the PET scans can be acquired in 2- or 3-dimensional mode using bismuth germanate oxide, gadolinium oxyorthosilicate, or lutetium oxyorthosilicate detectors. A detailed review of the basic principles of PET and CT imaging can be found in articles by Zanzonico (*5*) and Rydberg et al. (*6*), respectively.

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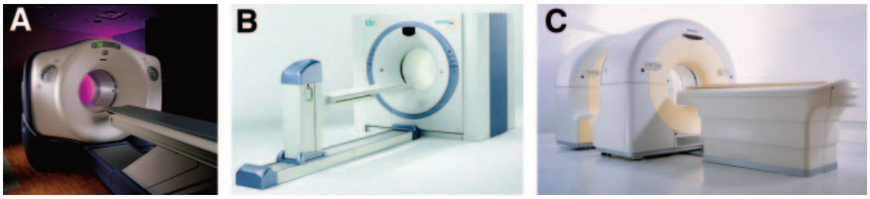

FIGURE 1. Current commercial PET/CT scanners from 3 vendors: Discovery ST (GE Healthcare) (A), Biograph Sensation 16 (Siemens Medical Systems) or Reveal XVI (CTI, Inc.) (B), and Gemini (Philips Medical) (C).

CT-BASED ATTENUATION CORRECTION

One main advantage of a PET/CT scanner is that it uses the CT image for attenuation correction of the PET data rather than relying on a rotating transmission rod source. Use of the CT scan reduces the total PET acquisition time and improves the precision of the attenuation correction factors (*3*). Upon completion of the CT scan, the CT attenuation coefficients corresponding to the different tissue types are mapped to their respective PET energies (511 keV) to generate a PET attenuation correction map. Different conversion methods are currently used to perform this task. One method, suggested by Kinahan et al. (*7*), segments the CT images to different tissue types and then scales each of the tissues to its corresponding PET values using predefined scaling factors (*7*). Another method, adopted by GE Healthcare, uses bilinear transformation, which can also be viewed as a combination of segmentation and scaling technique (*8,9*). In either method, the mapping is unique for the average CT peak kilovoltage used. Use of this mapping process on CT images acquired with different energies would require different lookup tables. During attenuation correction, the choice of the proper lookup table is vital to the technologist; the map is directly selected based on the CT peak kilovoltage used during data acquisition.

IMAGE ACQUISITION

A PET/CT imaging protocol usually calls for acquisition of a CT scout scan first, followed by a CT scan and a PET scan. The CT scout scan serves as an anatomic reference for the PET/CT scan. The technologist uses the scout scan to define the starting and ending locations of the actual CT and PET acquisitions. The CT scan is acquired over the range defined on the scout scan. CT scans are usually obtained using 100–140 kVp at various amperages, depending on the imaging protocol. Upon completion of the CT scan, the bed is automatically moved to position the patient in the field of view of the PET scanner. The patient is positioned so that the PET scan matches the same anatomic extent imaged during the CT acquisition. PET emission data are then acquired for 3–5 min per bed position covering the area of interest. The PET raw data are then reconstructed using the CT images for attenuation correction. CT scans are usually reconstructed in a 512×512 image matrix, whereas PET images are reconstructed in a matrix of 128×128. Upon reconstruction, both the PET images and the CT images are displayed side by side and overlaid (fused) (Fig. 2). This process can be done either on the same acquisition computer or on a different workstation, depending on the manufacturer.

IMAGING ARTIFACTS

The artifacts most commonly seen on PET/CT images are due to metallic implants, respiratory motion, contrast medium, and truncation. These artifacts occur because the CT scan is used instead of a PET transmission scan for attenuation correction of the PET data.

Metallic Implants

Metallic implants such as dental fillings, hip prosthetics, or chemotherapy ports result in high CT numbers and generate streaking artifacts on CT images because of their high photon absorption (*10,11*). This increase in CT (or Hounsfield) numbers results in correspondingly high PET attenuation coefficients, which lead to an overestimation of

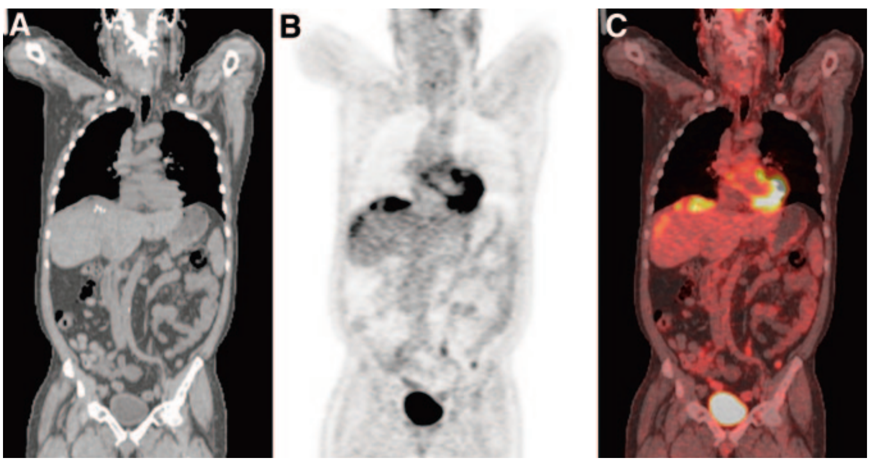

FIGURE 2. PET/CT image consisting of coronal whole-body CT image (A), PET image with CT attenuation correction (B), and fused image (C).

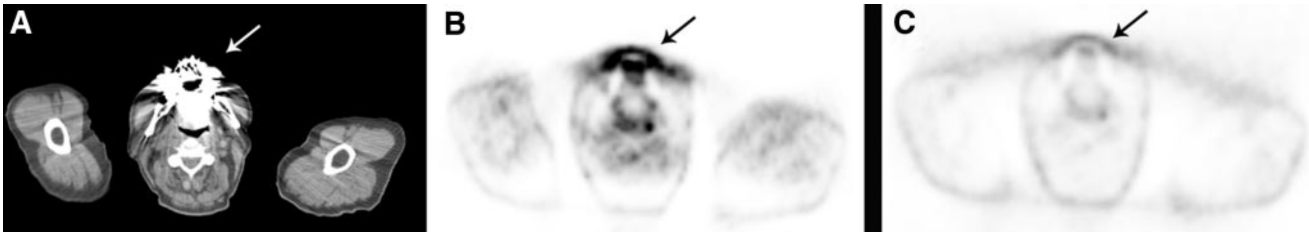

FIGURE 3. (A) High-density metallic implants generate streaking artifacts and high CT numbers (arrow) on CT image. (B) High CT numbers will then be mapped to high PET attenuation coefficients, leading to overestimation of activity concentration. (C) PET images without attenuation correction help to rule out metal-induced artifacts.

the PET activity in that region and thereby to a false-positive PET finding (Figs. 3 and 4). Nonattenuated PET images, which do not manifest this error, can be used in these cases to aid the interpretation of these metal-induced artifacts (*10–12*). Not all metallic implants produce false-positive PET results. High-density metallic implants such as hip prosthetics produce high CT numbers because of their high photon absorption (*13*). However, these implants also attenuate the PET 511-keV photons, resulting in no emission data in the region of the implant (cold area). When CT attenuation correction factors are applied to this photopenic emission region, the PET images show diminished ^{18}F-FDG uptake in that area (Fig. 5). As a result, technologists should ask patients to remove all metallic objects before imaging and should document the location of nonremovable metallic objects to minimize or identify such artifacts.

Respiratory Motion

Respiratory motion during scanning causes the most prevalent artifact in PET/CT imaging. The artifact is due to the discrepancy between the chest position on the CT image and the chest position on the PET image. Because of the long acquisition time of a PET scan, it is acquired while the patient is freely breathing (*14*). The final image is hence an average of many breathing cycles. On the other hand, a CT scan is usually acquired during a specific stage of the breathing cycle. This difference in respiratory motion between PET scans and CT scans causes breathing artifacts on PET/CT images. Several investigations have described this problem (*15–17*). To minimize the error, the current clinical protocol recommends that patients hold their breath at mid-expiration or mid-inspiration. Other protocols recommend acquiring the CT scan during shallow breathing. Both techniques, however, result in varying amounts of breathing artifacts (*15–17*). The shallow-breathing method does not accurately match the average PET image and degrades the CT image quality (*15–17*), whereas the breath-hold protocol produces artifacts if the patients fail to follow the breathing instructions correctly.

The most common type of breathing artifact results in curvilinear cold areas. This artifact appears when CT scans are acquired at full inspiration, which results in a downward displacement of the diaphragm because of the expansion of the lungs. This downward displacement causes the CT attenuation coefficients in the normal location of the diaphragm region to be underestimated because they represent air rather than soft tissue (*17*). The resulting underestimation of activity on the PET image thereby produces a curvilinear cold area at the lung–

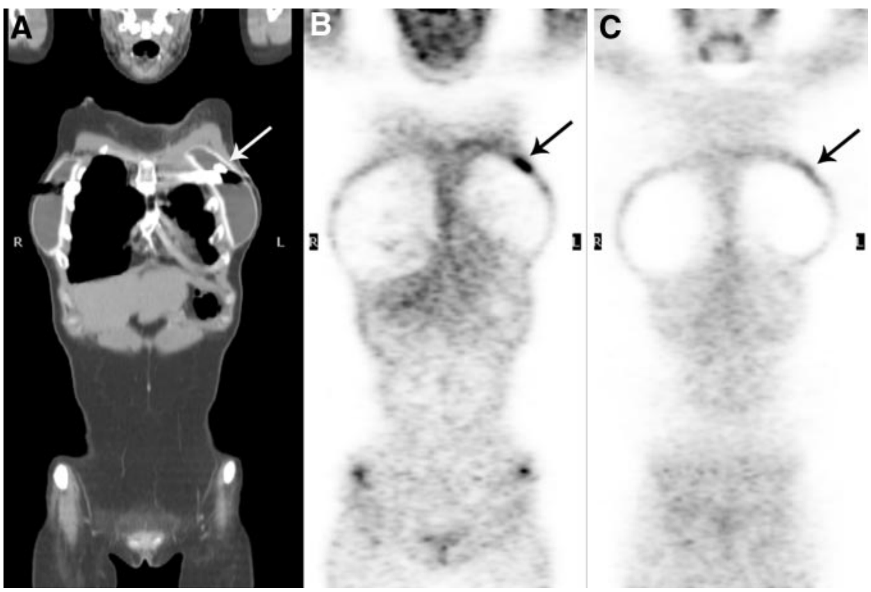

FIGURE 4. Metal ring on left breast of patient (arrow) produces streaking artifacts and high CT numbers (A), resulting in falsely increased radiotracer uptake on PET images with CT attenuation correction (B), whereas PET image without attenuation correction shows only background activity at level of metal ring (C).

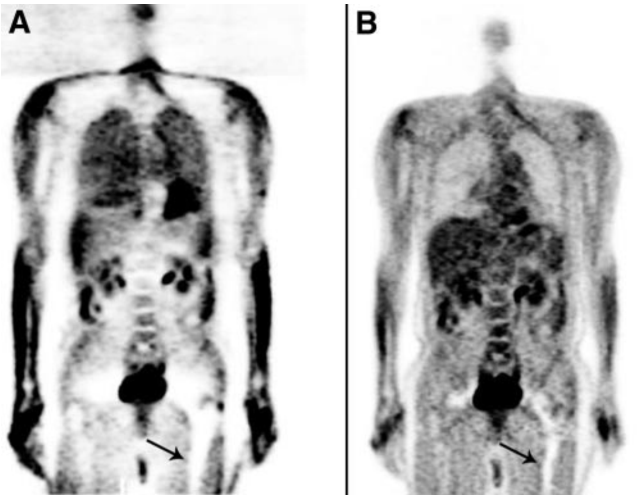

FIGURE 5. (A) Hip prosthesis produces photopenic area (arrow) on PET image without attenuation correction because of photon absorption. (B) No radiotracer uptake is seen on PET image with attenuation correction.

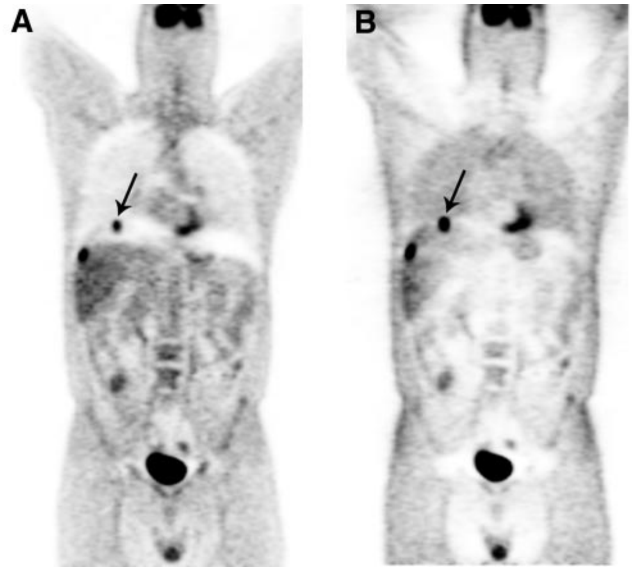

FIGURE 7. (A) 58-y-old man with colon cancer. Lesion at dome of liver is mislocalized to right lung (arrow) because of respiratory motion. (B) Image without attenuation correction shows that all lesions are confined to liver.

diaphragm interface (Fig. 6). Additionally, this type of artifact can have a profound impact on patients with proven liver lesions. Because of the respiratory motion, a liver lesion can erroneously appear at the base of the lung, mimicking a lung nodule (*15*). This artifact is usually referred to as a misregistration of lesions (Fig. 7). Review of the CT images for an anatomic abnormality in the lung or liver is usually sufficient to confirm that respiratory misregistration has occurred. Inaccurate attenuation correction values for lung lesions are another consequence of mismatches between the CT and PET images due to respiratory motion. These mismatches, in turn, result in erroneous standardized uptake values in PET attenuation-corrected images (Fig. 8). Therefore, it is essential that technologists instruct patients about breath-hold techniques before the scanning session in order to minimize artifacts and produce accurately quantifiable images.

Contrast Media

Intravenous or oral contrast agents such as iodine and barium sulfate are administered to patients to enhance CT images by delineating vessels and soft tissues (*18*). Though improving the quality of CT images, contrast material affects the quantitative and qualitative accuracy of PET images in a manner similar to that of metallic implants (*18,19*). High contrast concentrations result in high CT numbers and streaking artifacts on CT images because of photon absorption (*18,19*). This increase in CT numbers also results in high PET attenuation coefficients, leading to an overestimation of tracer uptake, thereby producing false-positive PET results. The severity of the contrast-agent artifact on PET images with CT attenuation correction depends on the concentration of the administered contrast agent, its distribution and clearance, and the time between its administration and the CT acquisition (*18–20*). For example, the concentration of oral contrast agent increases with time because of signif-

FIGURE 6. Curvilinear cold artifact (arrow) is commonly seen on dome of diaphragm/liver or at lung base because of respiration mismatch on PET images with CT attenuation correction.

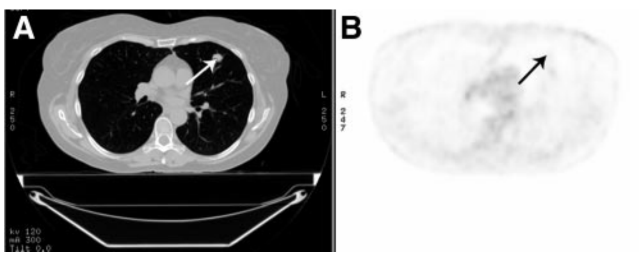

FIGURE 8. Mismatch of lesion localization between CT and PET scans. Lesion (arrow) seen on upper left lung of CT transaxial image (A) is not present on corresponding PET image (B), creating inaccurate attenuation correction values for that lesion.

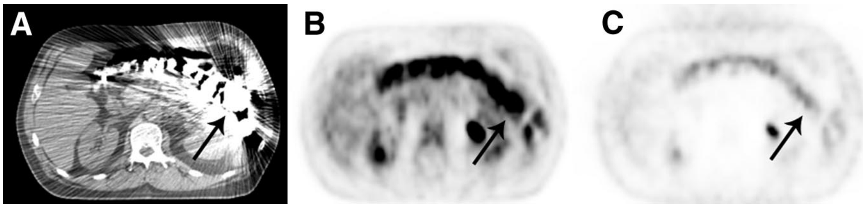

FIGURE 9. (A) 61-y-old patient with lung cancer who ingested barium for an esophagogram 1 d before PET/CT scan. Concentration of contrast medium in colon (arrow) increased because of significant water reabsorption, shown on CT image. (B) High CT numbers of residual barium overcorrect attenuation of PET emission data and mimic increased ^{18}F-FDG uptake on PET image with CT attenuation correction. (C) No increased ^{18}F-FDG uptake is seen on image without attenuation correction.

icant water reabsorption. As a result, the high CT numbers of the residual barium overcorrect the attenuation of the PET emission data and mimic an increase in tracer uptake, affecting the interpretation of the PET scan (Fig. 9) (*18–20*). Non–attenuation-corrected PET images are usually consulted in this case to avoid false-positive PET findings (*18–20*). Therefore, when scheduling patients for PET/CT scans, technologists should be cognizant of the patient's prior CT scan appointments. It is not advisable to schedule PET/CT scans for patients who have undergone CT with oral contrast agent the previous day.

CT with intravenous contrast agent, on the other hand, has a minimal effect on the PET images (*21*). Because of the faster clearance and dilution of intravenous contrast agents, they have a low concentration at the time of the CT scan, thereby minimally affecting the quality of the CT-attenuation-corrected PET images (Fig. 10).

Truncation

On dedicated PET scanners, patients are usually scanned with their arms at their sides because the scanning sessions are lengthy. However, in PET/CT imaging, patients are usually scanned with their arms above their head to prevent truncation artifacts (*22,23*). Truncation artifacts in PET/CT are due to the difference in size of the field of view between the CT (50 cm) and PET (70 cm) tomographs (*22,23*). These artifacts are frequently seen in large patients or patients scanned with arms down, such as in the case of melanoma and head and neck indications. When a patient extends beyond the CT field of view, the extended part of the anatomy is truncated and consequently is not represented in the reconstructed CT image. This, in turn, results in no attenuation correction values for the corresponding region in the PET emission data, hence introducing a bias on the PET attenuation-corrected images that underestimates the standardized uptake values in these regions (Fig. 11). Truncation also produces streaking artifacts at the edge of the CT image, resulting in an overestimation of the attenuation coefficients used to correct the PET data. This increase in attenuation coefficients creates a rim of high activity at the truncation edge, potentially resulting in misinterpretation of the PET scan. Therefore, in PET/CT imaging, it is crucial that technologists carefully position patients at the center of the field of view and with arms above head to reduce truncation artifacts.

CONCLUSION

PET/CT imaging resolves the limitations of dedicated PET by making use of a rapid low-noise CT scan for attenuation correction, thereby improving image quality while decreasing patient discomfort and increasing patient throughput. In addition, PET/CT imaging increases the accuracy of diagnosis by combining anatomic information with functional imaging. PET/CT imaging is highly dependent on a host of technical considerations. Knowledgeable technologists can minimize artifacts and other potential problems with image acquisition and, in that way, produce better-quality PET/CT images.

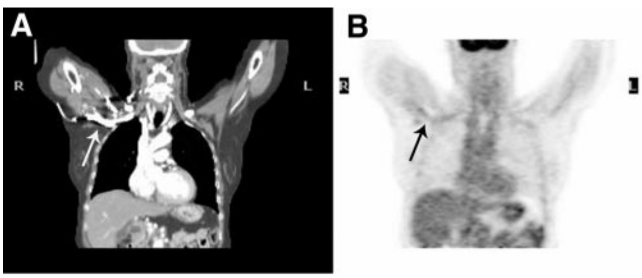

FIGURE 10. (A) CT scan shows intravenous contrast medium in right subclavian vein (arrow). (B) Radiotracer uptake is increased in corresponding region of PET image but does not change clinical diagnosis.

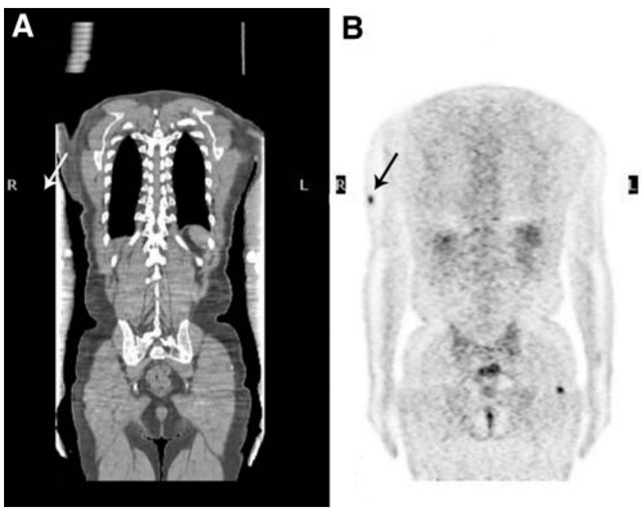

FIGURE 11. 54-y-old man with history of metastatic melanoma (arrow). CT image appears truncated at sides (A) and biases PET attenuation-corrected image (B).

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