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PET/CT Artifacts

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Abstract

There are several artifacts encountered in PET/CT imaging, including attenuation correction (AC) artifacts associated with using CT for attenuation correction. Several artifacts can mimic a 2-deoxy-2-[18F] fluoro-D-glucose (FDG) avid malignant lesions and therefore recognition of these artifacts is clinically relevant. Our goal was to identify and characterize these artifacts and also discuss some protocol variables that may affect image quality in PET/CT.

Keywords

PET/CT; artifact; attenuation correction; image quality; protocol variable

INTRODUCTION

There are several artifacts inherent to FDG PET imaging that have been reported in the literature, including photopenic areas due to metallic devices or other high attenuation materials (1, 2). There are several PET/CT artifacts as well; however, their appearances are different than those seen on dedicated PET scanners, and there are a number of new artifacts that are unique to combined PET/CT scanners. Most of these unique artifacts are generated by the CT-based AC protocol that is currently in use in most PET/CT scanners. This article will discuss the most common typical and atypical appearances of artifacts encountered in PET/CT imaging and some potential solutions to avoid or correct them. In addition, it will also include a discussion of the most common non-AC-related PET/CT artifacts.

CT ATTENUATION-CORRECTION AND RELATED ARTIFACTS

There are several AC methods for PET and PET/CT scanners (3–6). One of the advantages of using PET/CT is that the AC is easily performed using the CT portion of the exam, rather than having to perform a separate transmission scan, which is necessary to perform AC on

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dedicated PET systems. Using CT for AC thus permits a significant reduction in the amount of time it takes to complete an exam. Although counterintuitive, it may take up to 40% less time to complete a whole body PET/CT scan than it does to complete a dedicated PET study. Furthermore, Halpern et al have described a weight-based protocol, in whom patients below 59 kg can be scanned in approximately 7 minutes (1 minute for CT and 6 for PET using 6 bed positions at 1 minute per bed position) without any diagnostic compromise (using LSO crystal technology) (7).

However, when using CT-based AC, the measured CT Hounsfield units (HU), related to the linear attenuation seen by the x-ray beam, must be transformed into the corresponding quantity at the higher PET photon energy of 511 keV. Most current CT-based AC algorithms either segment image pixels into soft tissue or bone based on the HU and transform those tissues using unique scale factors (5), or treat image pixels as a mixture of two well-defined materials and transform them accordingly (Figure 1) (6). These AC algorithms work well for most applications in the majority of patients. However, these algorithms tend to overcorrect objects, including contrast agents, chemotherapy ports and other dense structures that have higher HU but are not true bone pixels. Many of the AC artifacts encountered are typically readily appreciated by the experienced reader; however, occasionally these artifacts can have atypical appearances leading to a more challenging interpretation (8).

INTRAVENOUS CONTRAST AND AC ARTIFACTS

There are three primary ways to perform the CT portion of a combined PET/CT examination. It can be done with: 1) low current (~40mAs), in which the CT is used primarily for AC and localization, 2) normal current (~140mAs) with IV and/or oral contrast, and 3) a double CT with both low dose (for AC) and repeat CT with full current (for diagnostic interpretation) (9). One of the reasons why the use of contrast agents with PET/CT are controversial is that they may cause AC artifacts on the corrected PET images when using CT for AC (8, 10–13). The reasoning for performing a non-contrast CT and a contrast-enhanced CT (in method #3 above) is to avoid many of the artifacts secondary to IV and oral contrast. When dense contrast material is present in venous structures during the CT acquisition there tends to be an overcorrection of the PET data. This mismatch causes areas of linear artifact (mimicking intense FDG accumulations) on the AC PET images (Figure 2) (14). Occasionally, these artifacts are clinically significant when they are in the vicinity of a real lesion. Atypically, this artifact can appear focal and mimic a metastatic lymph node in the axilla or supraclavicular area (Figure 3) (8). For instance, a small malignant lymph node or small soft-tissue abnormality can lie within or directly adjacent to a contrast artifact, partially or completely obscuring the abnormality (14). In addition, artifacts can have atypical appearances that can confound image interpretation (Figure 4). A relatively simple solution to diagnostic uncertainty regarding the presence of a CT-based AC artifact is to inspect the non-AC PET images. Unfortunately, it can be cumbersome to switch between the AC and non-AC PET data using many PET/CT viewing systems; and some fusion viewing systems will not allow side-by-side comparison of AC and non-AC PET images.

One way to avoid CT-based AC artifacts due to IV contrast is to perform a low dose non-contrast CT that can be used for AC first. Then, following the PET portion of the exam, a contrast-enhanced CT can be done for diagnostic purposes. However, depending on the CT parameters used, this dual-CT approach usually results in an increase in the radiation exposure to the patient (15).

In summary, there is no “right” way to perform the CT portion of a PET/CT scan. Whether to give contrast will also depend in large part on the clinical indication, as well as on adequate physician and technologist coverage. Another issue to consider is whether the patient will be billed for the CT portion of the exam. However, pitfalls associated with IV contrast AC artifacts can be minimized either by inspection of the non-AC PET images and/or by adding a non-contrast CT for AC.

A software solution with a new CT-based AC algorithm that does not generate artifacts is certainly the most appealing solution for AC artifacts. A possible approach to this problem presents itself by noting that the use of an AC with inaccuracies results in an image set (attenuation and emission image) that is less consistent with the measured sinogram than is the image set obtained with the correct attenuation. Efforts to exploit this consistency difference are being investigated. In one method, artifact identification and correction algorithms based on the likelihood function, a function of the image set values and the measured sinogram, are used. A second, related method is also being studied in which identification and correction algorithms are based on a calculation of the internal consistency of the attenuation-corrected sinogram. This work is at an early stage of development but has shown promising results. These methods could be used in conjunction with other methods for artifact correction.

ORAL CONTRAST AND AC ARTIFACTS

Several oral contrast agents are available for clinical use in diagnostic imaging. In general, barium or iodine-based oral contrast agents that are highly attenuating at CT energies will tend to cause some degree of AC artifact on the PET images, while negative or water-based oral contrast agents generally do not (16–22). Most of the time, there is overlap of physiologic and artifactual bowel activity, and as long as the appearance of bowel activity is linear, it typically is of limited clinical importance. However, when the oral contrast AC artifacts are more focal or irregular, they can be a diagnostic challenge. It is imperative to check the non-AC PET images in these instances to be sure that a suspected lesion is not an AC artifact (Figure 5).

A study from Essen, Germany has reported that the use of oral contrast media does not usually cause clinically significant AC artifacts (22); however, it has also been noted by a different group that areas of barium-based oral contrast material within the bowel can cause artifacts and overestimate FDG activity in the bowel by as much as 20% (22, 23). In the case of oral contrast agent, adopting a region growing approach appears to correct most, if not all CT-based AC artifacts (Figures 6–7). However, no PET/CT scanners to date use this alternative method of AC. Another approach is to transform all higher HU as if they were enhanced due to contrast agents, though this approach is necessarily a compromise as values

corresponding to bone will be transformed incorrectly, and it is not always clear for enhanced structures what the HU would be in the absence of enhancement.

There remains some debate about the added clinical value of oral contrast with PET/CT given the additional information that is obtained by having FDG from the PET portion of the exam. However, when there are focal or irregularly-shaped areas of FDG uptake in the abdomen adjacent to a loop of bowel, having well-opacified bowel may be essential for differentiating physiologic from pathologic uptake. It may be helpful to create contrast protocols based on indications, where patients being evaluated for head and neck cancer and other malignancies in which the incidence of abdominal and pelvic metastases is less would be done without oral contrast, while any patient being evaluated for an abdominopelvic malignancy would be given oral contrast.

PORTS AND OTHER HIGH ATTENUATION DEVICES

Metallic objects, including various orthopedic devices and chemotherapy ports typically cause areas of photopenia on images obtained on a dedicated PET scanner. When correcting for attenuation with Germanium or other point sources, these areas remain photopenic on the AC images. In contrast, when using the current CT-based AC algorithms, these areas usually demonstrate falsely elevated FDG uptake (Figure 8) (13, 24–26). It is usually easy to correlate the area of apparent FDG uptake with the metallic device on PET/CT by inspecting the fused PET/CT images. However, clinically relevant lesions adjacent to a port or metallic device can be more difficult to detect. Also, increased uptake around prosthetic devices on PET/CT due to small amounts of patient movement between the CT and PET portions of the exam can easily be misinterpreted as infection or loosening (Figure 9) (26).

In addition, some dental implants or fillings can also cause an AC artifact and can severely confound image interpretation by obscuring real lesions or creating apparent lesions (artifacts) in patients with head and neck malignancies involving the oral cavity or tonsils (Figure 10) (13, 24).

CALCIFIED LYMPH NODES AND AC ARTIFACTS

Perhaps the most clinically significant but underreported CT-based AC artifacts are ones caused by calcified lymph nodes (Figure 11). This is particularly true, for example, in a patient who is being evaluated for lung cancer and has falsely elevated uptake of FDG in a normal calcified lymph node. In a patient with a right-sided primary squamous-cell carcinoma of the lung and a single contralateral calcified paratracheal lymph node with falsely elevated FDG uptake, this could lead to non-surgical management (Stage IIIB) if the artifact is not suspected. A high degree of clinical suspicion should be maintained when calcified lymph nodes are seen on the CT portion of the exam, because unlike many other AC artifacts (e.g. IV contrast), these have more focal configurations (rather than linear) of apparent FDG uptake. However, as with the other AC artifacts, it is relatively easy to prove the presence of an AC artifact caused by a calcified lymph node by careful inspection of the non-AC PET images (as long as it is suspected).

DIAPHRAGMATIC RESPIRATORY ARTIFACTS

Non-AC-based artifacts specific to PET/CT imaging have also been observed. Diaphragmatic motion during the CT acquisition can cause large portions of the liver to appear displaced to the thorax (Figure 12) (27–30). Because CT is typically acquired with deep inspiration and PET is typically acquired during tidal respiration, there is an inherent mismatch in the diaphragmatic position, which is most severe when the patient is instructed to hold their breath in deep inspiration. The magnitude of these diaphragmatic breathing artifacts is dependent on how long it takes to acquire the data in this region as well as the breathing instructions given to the patient. Therefore, with single and dual-slice CT scanners, this artifact is seen in up to 80% of patients when the CT data is acquired with tidal breathing (29, 31). This number is much less with 16-slice CT scanners where the data acquisition time is significantly reduced. Another way to reduce breathing artifacts is to use a modified breathing algorithm as described by Beyer et al (29). This algorithm involves instructing the patient to breathe with shallow tidal respiration until the detector is near the bottom of the thorax, at which time the patient is instructed to stop breathing wherever they are in their respiratory cycle until the detector has passed through the liver. Breath-holding until the CT detectors are through the liver minimizes respiratory motion and thus reduces subsequent diaphragmatic breathing artifacts.

These diaphragmatic artifacts are the most clinically significant when there are lesions in the superior liver or in the lower thorax. Often lesions in these areas will be improperly displaced on one modality to the wrong location or even to the wrong organ, which can lead to misdiagnosis (32). Radiotherapy applications also become significantly more difficult because of the mismatch in the anatomical structures. Some groups have begun work evaluating respiratory and cardiac gating for radiation purposes to reduce the amount of normal tissue exposure and improve the accuracy of radiation delivery to the affected areas (33).

Breathing artifacts can also be clinically significant if they obscure, either wholly or partially, a lesion that could be misconstrued as simply artifact (Figure 13). Many of these lesions within or adjacent to an artifact can easily be overlooked without systematic inspection of the non-AC PET images on every patient where an artifact is suspected.

OTHER VARIABLES AFFECTING IMAGE QUALITY

LYMPHANGIOGRAM EFFECT—The FDG used for PET studies is injected intravenously into patients. Occasionally, a portion or the entire dose may be infiltrated accidentally into the subcutaneous tissues. When this occurs, FDG may be taken up into the lymphatic system. This can be problematic because it can cause eventual uptake within axillary or mediastinal lymph nodes and make the study essentially non-diagnostic due to the inability to exclude nodal disease (Figure 14) (34). This often requires a short-term follow-up exam to ensure the absence of disease, particularly in patients with breast or lung cancer, where accurate assessment of nodal disease can have drastic clinical implications regarding treatment and staging.

PATIENT SIZE AND IMAGE QUALITY—One of the most important determinants of image quality is patient size. In smaller patients, there is much less photon attenuation leading to a large increase in image clarity. As patient weight and/or size increases, image quality generally decreases with similar scan parameters on the same scanner (Figure 15).

ARM POSITIONING AND IMAGE QUALITY—Unlike dedicated CT, where short scan times allows for routine scanning with the arms kept out of the field of view, with PET/CT the arms may often be kept in the field of view to minimize patient discomfort and the potential for motion artifacts. When the arms are positioned at the patient's side, there can be significant beam hardening and streak artifacts in the CT images (Figure 16), which can be especially problematic when the artifact overlaps with the area of interest. One potential solution is to scan all patients with arms up, thereby excluding such artifact from the chest and abdomen. In patients with head and neck malignancies or clinical concern of neck involvement, a second focused exam of the neck can be performed with the arms down if there is artifact in the neck area with the arms in the up position.

GLUCOSE, INSULIN AND IMAGE QUALITY—Diabetic patients and other patients with conditions causing temporarily elevated blood glucose levels are a challenge for physicians referring or interpreting PET or PET/CT scans. Because FDG competes with glucose for intracellular entry, when blood glucose levels are elevated, less FDG enters cells and more is excreted in the urine. Therefore, in general, as blood glucose levels increase, image quality decreases. It may seem logical, then, that giving insulin to reduce blood glucose levels prior to FDG injection may improve image quality. However, insulin not only facilitates glucose entry into cells, it also facilitates FDG entry into adipose and muscle cells preferentially (Figure 17). This can cause diffuse linear FDG uptake within skeletal muscle and make identification of a lesion that may be located next to muscle difficult to visualize. Unfortunately, there is no good way to quickly reduce glucose levels and typically good-quality FDG PET and PET/CT scans rely on good glucose management prior to being scanned.

CONCLUSION

There are several artifacts unique to combined PET/CT imaging, including AC-based artifacts as well as protocol-based artifacts. For the experienced reader, many typical appearances of these artifacts will not be clinically significant. However, atypical patterns of artifacts even for the experienced reader can be challenging. For the inexperienced reader, it is imperative to become familiar with the common and atypical appearances of the most common artifacts and be diligent about inspecting the non-AC PET images when an AC artifact is suspected.

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Figure 1. Current CT based attenuation correction algorithm

The transformations in current CT-based attenuation correction algorithms used to convert Hounsfield units into 511 keV linear attenuation values for attenuation correction in PET. The threshold model (solid line) is described in (5) and the mixing model (dashed line) is described in (6). Both perform well in transforming bone and soft tissue values.

Figure 2. Linear IV Contrast AC Artifact

Coronal PET image (a) shows a focal area of apparent FDG uptake in the left axilla that would be suspicious for a lymph node (arrow). Inspection of the axial CT, fused PET/CT and AC PET images (b–d) show that the area of FDG activity to be linear and in the area of the IV contrast in the left subclavian vein (arrows). The non-AC PET image (e) proves that the apparent FDG activity is an AC artifact only seen on AC PET and AC PET/CT fused images.

Figure 3. Focal IV Contrast AC Artifact Mimicking Small Lymph Node

All images except the axial non-AC PET image (a–d) show a focal area of apparent FDG activity in the area of the right brachiocephalic vein (arrow). Inspection of the non-AC PET image (e) shows no FDG activity proving this focal area of otherwise suspicious FDG activity to be an AC artifact.

Figure 4. Focal IV Contrast AC Artifact Mimicking Nodal Spread

Coronal PET image (a) shows apparent nodal spread (arrows) adjacent to and to the left of a primary squamous cell carcinoma of the larynx (arrowhead). Axial CT and fused PET/CT images (b,c) show the apparent focal area of intense FDG uptake to correlate to part of an area of IV contrast in the left subclavian area (arrow). Although there is apparent FDG activity on the AC PET image (d), the non-AC PET image (e) shows no FDG activity in this area compatible with a focal IV contrast AC artifact.

Figure 5. Two Focal Oral Contrast AC Artifacts

Axial CT (a,d), fused PET/CT with AC PET (b,e), and fused PET/CT with non-AC PET (c,f) images show two areas of dense contrast remaining in the bowel after an upper GI performed with barium (arrows). The fused PET/CT with non-AC PET shows no FDG activity in the artifactual areas that appear to have very intense FDG uptake on the fused PET/CT with AC PET. This is a good example of an oral contrast AC artifact.

Figure 6. Modified AC Algorithm

Depiction of a software-based modified AC algorithm applied to oral-contrast enhanced studies. True bone voxels in the CT images are segmented from oral-contrast enhanced voxels using a region-growing algorithm, followed by the replacement of the enhanced voxels with the HU for water. Finally, the modified CT images can then be transformed in the usual way appropriate for bone and soft tissue (e.g. using one of the methods in Figure 1).

Figure 7. Oral Contrast AC Artifact

Coronal CT image showing an area of high attenuation material in the stomach (arrow, close to ~3000 HU). Non-AC coronal PET image shows no significant activity (arrow). Using the standard AC algorithm, there is a focal area of apparent FDG activity corresponding to the area of high attenuation material (AC, arrow). Using the modified AC algorithm of Figure 6, this area is correctly displayed without focal FDG activity (Modified AC).

Figure 8. CT AC Artifact From Port

Coronal PET, axial CT and fused PET/CT images (a–c) show a focal area of intense FDG accumulation (arrows) that appears to correlate to the area of a chemotherapy port in the right upper chest wall. Although present on the axial AC PET image (d), the non-AC image (e) shows correctly that this area is an AC artifact due to the high attenuation composition of the material in the port.

Figure 9. Orthopedic Device Causing AC Artifact

Coronal PET (a) demonstrates apparent areas of intense FDG uptake (arrows) that correlate to a metallic left hip prosthesis on CT and fused PET/CT images (b–c). AC PET (d) shows a focal area of apparent FDG activity lateral to the prosthesis, but inspection of the non-AC image (e) shows the area in question to be an AC artifact. This could easily be mistaken as inflammation, loosening or infection around the prosthesis.

Figure 10. Dental Hardware AC Artifact

Coronal PET (a) demonstrates areas of intense FDG accumulation in the area of the oral cavity (arrow). Axial CT and fused PET/CT with AC PET (b,c) show the apparent uptake to correlate to areas of streak artifact on CT from dental fillings. Non-AC PET (d) shows areas of photopenia proving these areas on the attenuation corrected coronal PET to be an artifact generated during the attenuation correction process.

Figure 11. Calcified Lymph Node With AC Artifact

Coronal AC PET image (a) shows a focal area of intense FDG uptake in the subcarinal area (arrow). CT and Fused PET/CT images (b,c) show the area of uptake to correspond to a calcified subcarinal lymph node (arrows). The non-AC PET image (e) shows no evidence of FDG activity in the suspected area proving the area to be an AC artifact.

Figure 12. Respiratory Diaphragmatic Artifact

Coronal PET, CT and PET/CT images (a–d) show severe displacement and apparent detachment of a large portion of the liver (arrows) from using tidal respiration breathing protocol during the CT acquisition.

Figure 13. Focal Bronchioloalveolar Cell Carcinoma Adjacent to Breathing Artifact

Coronal PET, CT and fused PET/CT images and axial fused PET/CT image (ad) from a combined PET/CT exam show an area of FDG uptake (arrows) adjacent to a small diaphragmatic breathing artifact in which the top of the liver appears to be displaced into the thorax. Although easily overlooked because of its proximity to the artifact, this abnormality was eventually biopsied because it did not resolve over time. The biopsy was positive for bronchioloalveolar cell carcinoma.

Figure 14. Lymphangiogram Effect

Coronal PET images (a–c) show infiltration of FDG dose in the left forearm and subsequent uptake into the lymphatics (arrows) as well as several axillary and mediastinal lymph nodes (arrowhead). Although the FDG activity in the nodes was secondary to the infiltrated dose, the patient was brought back for a repeat scan two weeks later because of the inability to differentiate between FDG taken up by the lymphatics versus malignant lymph nodes. The follow-up scan was negative.

Figure 15. Effect of Patient Size on Image Quality

Coronal PET images (a–c) from 3 patients of varying weight shows severe degradation of image quality in a patient weighing 142 kg (c) compared to patients weighing 61 (a) and 103 (b) kg acquired with similar imaging protocols and on the same scanner.

Figure 16. Effect of Arm Positioning on Image Quality

Coronal (b,d) and axial (a,c) CT images in the same patient with arms up and arms down show significant beam hardening artifact and image quality degradation with arms up compared to that of arms down.

Figure 17. Glucose, Insulin and Image Quality

Coronal PET/CT (a) and axial CT and fused PET/CT (b,c) images in a patient with an elevated blood glucose level who was given IV insulin in an attempt to bring blood glucose levels down. Note the multiple linear areas of intense FDG accumulation corresponding to areas of muscle (arrows). This is because insulin has the same effect on FDG that it does on glucose; it facilitates the entry of both into muscle and fat cells.