

Respiratory motion artifacts on PET emission images obtained using CT attenuation correction on PET-CT

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Abstract. PET-CT scanners allow generation of transmission maps from CT. The use of CT attenuation correction (CTAC) instead of germanium-68 attenuation correction (Ge AC) might be expected to cause artifacts on reconstructed emission images if differences in respiratory status exist between the two methods of attenuation correction. The aim of this study was to evaluate for possible respiratory motion artifacts (RMA) in PET images attenuation corrected with CT from PET-CT in clinical patients. PET-CT scans were performed using a Discovery LS PET-CT system in 50 consecutive patients (23 males, 27 females; mean age 58.2 years) with known or suspected malignancy. Both CTAC and Ge AC transmission data obtained during free tidal breathing were used to correct PET emission images. Cold artifacts at the interface of the lungs and diaphragm, believed to be due to respiratory motion (RMA), that were seen on CTAC images but not on the Ge AC images were evaluated qualitatively on a four-point scale (0, no artifact; 1, mild artifact; 2, moderate artifact; 3, severe artifact). RMA was also measured for height. Curvilinear cold artifacts paralleling the dome of the diaphragm at the lung/diaphragm interface were noted on 84% of PET-CT image acquisitions and were not seen on the ⁶⁸Ge-corrected images; however, these artifacts were infrequently severe. In conclusion, RMA of varying magnitude were noted in most of our patients as a curvilinear cold area at the lung/diaphragm interface, but were not diagnostically problematic in these patients.

Keywords: PET/CT – Image fusion – Artifact – Respiratory motion

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Introduction

Positron emission tomography (PET) provides unique information regarding tumor biology, but the lack of anatomical landmarks on PET can make precise lesion localization challenging. Software image fusion can be applied to address this problem but is often logistically challenging owing to differences in the patient's positioning between studies. PET-CT systems can acquire anatomical and functional information in the same examination in very close temporal proximity [1]. In such systems, CT data can be used for PET attenuation correction (AC) instead of the traditionally used germanium-68 and is much faster [2].

Artifacts originating from the use of CT data for AC, rather than ⁶⁸Ge transmission data, are not yet well characterized. While translation of the patient's body between PET and CT is a possible source of misalignment, physiological activities like breathing might also result in artifacts. Artifacts might be expected if differences in respiratory status were to exist between the PET and CT images. For example, if the lungs were to be more inflated on CT than on PET, an attenuation value derived from the lung (which has low attenuation) might be applied to the upper liver, resulting in underestimation of the upper liver's true radioactivity level. The purpose of this study in clinical patients was twofold: (a) to evaluate whether respiratory motion artifacts (RMA) exist at the level of the interface of the diaphragm and lung in PET images that have been attenuation corrected with CT from PET-CT and (b) to compare these images with images attenuation corrected using ⁶⁸Ge transmission images, the historical standard.

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Materials and methods

Patients. Images from 50 (23 males, 27 females; mean age 58.2 years) sequential clinical patients who underwent PET-CT scans (GE Discovery LS PET-CT system) in our institution for known or suspected cancer were assessed.

PET-CT scanning. After 4 h of fasting, approximately 555 MBq of fluorine-18 fluorodeoxyglucose (FDG) was injected intravenously, followed by an approximately 55-min uptake phase. Patients were given no specific breathing instructions during the image acquisition (tidal breathing expected).

CT scanning. Parameters were as follows for 5–7 bed acquisitions: 140 kV, 80 mA, 0.8 s per CT rotation, pitch of 6, 22.5 mm/s table speed, 722.5–1011.5 mm coverage, 31.9–37 s acquisition time. CT acquisition was performed before emission acquisition. Five-millimeter-thick sections were re-sliced to 4.25 mm in thickness. CT data were resized from 512×512 matrix to a 128×128 matrix to match PET data in order to fuse images and generate CT transmission maps.

PET scanning and image processing. Emission data were acquired for 5–7 bed positions, typically from the base of the skull through the mid-thigh (722.5–1011.5 mm coverage, identical to the CT protocol). Emission data were acquired for 5 min for each bed position (35 scanning planes, 14.6 cm longitudinal field of view, one slice overlap). Images were reconstructed with an 8-mm Gaussian filter using a 128×128 matrix. PET images were reconstructed using CT (CTAC) with OSEM iterative reconstruction algorithm (2 iterations, 28 subsets). Emission data were also reconstructed with segmented ^{68}Ge AC (3 min/level transmission data).

Image analysis. Both CTAC and Ge AC images were independently evaluated for the presence of RMA, a cold curvilinear defect at the interface of the lower lung and diaphragm. RMA was qualitatively rated on a four-point scale (0, no artifact; 1, mild artifact; 2, moderate artifact; 3, severe artifact) by one observer (M.O.). RMA was also quantified as the vertical distance between the top and bottom of the cold artifact (located at the apparent interface of the lower lung and diaphragm) in the right lung (anterior, middle, posterior) and the left lung (posterior only owing to the heart). To quantify the RMA, the mid-plane of the chest was visually located on the relevant coronal PET views and measurements were made on the sagittal views (Fig. 1). Upper and lower regions of interest were placed to define the extent of the artifact, and the cranial caudal extent of the cold defect was measured.

Results

Curvilinear cold artifacts paralleling the dome of the diaphragm at the apparent lung/diaphragm interface were commonly noted on PET-CT image acquisitions but were not seen on the ^{68}Ge -corrected acquisitions (Fig. 1). In the right lung, 8 patients (16%) had no RMA, 33

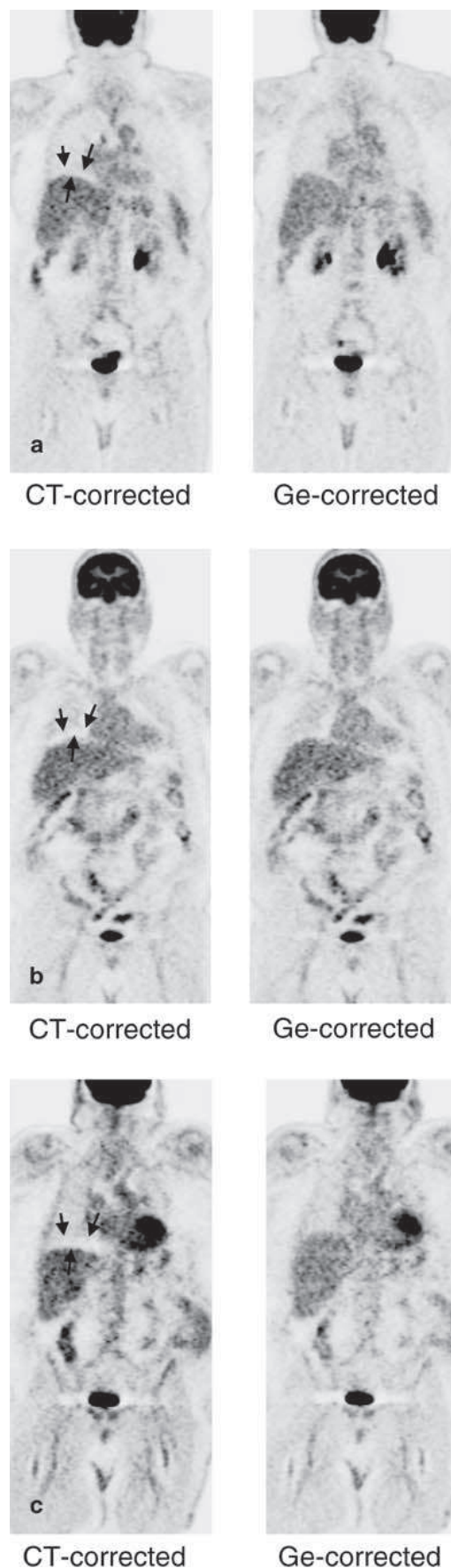


Fig. 1a–c. Examples of mild (a), moderate (b), and severe (c) RMA on CT-corrected emission FDG-PET images and comparative ^{68}Ge -corrected images of the same patients

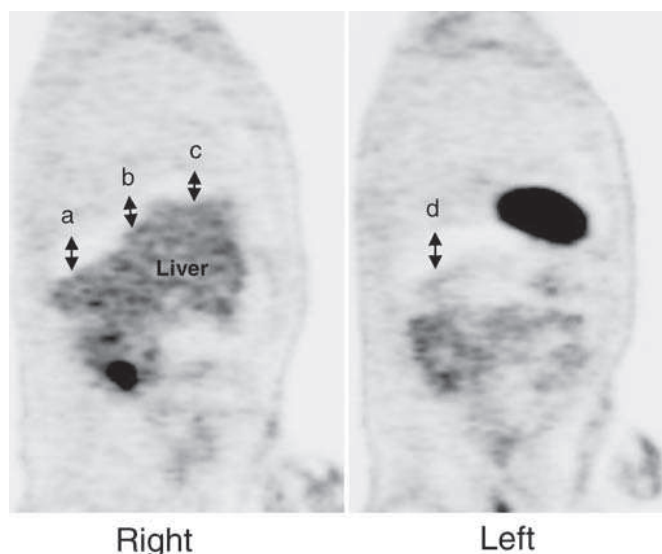


Fig. 2. Examples of quantitative assessment of RMA. In the right lung: *a*, posterior; *b*, middle; *c*, anterior; in the left lung: *d*, posterior

Table 1. Qualitative assessment of RMA using a three-point scale

Extent of RMA	Right lung	Left lung
Absent (0)	8 pts (16%)	8 pts (16%)
Mild (1)	33 pts (66%)	31 pts (62%)
Moderate (2)	8 pts (16%)	6 pts (12%)
Severe (3)	1 pt (2%)	5 pts (10%)

Table 2. Quantitative assessment of RMA

Site of RMA measurement	Right lung	Left lung
Anterior	16.4±10.5 mm	Not measured
Middle	14.3±7.6 mm	Not measured
Posterior	13.6±8.6 mm	17.8±10.8 mm

(66%) had mild RMA, 8 (16%) had moderate RMA, and one (2%) had severe RMA. In the left lung, 8 patients (16%) had no RMA, 31 (62%) had mild RMA, 6 (12%) had moderate RMA, and 5 (10%) had severe RMA (Table 1). Figure 1 shows examples of mild (*a*), moderate (*b*), and severe (*c*) RMA and comparative ^{68}Ge -corrected images for the same patients.

RMA was quantified on the sagittal view (Fig. 2). RMA was 16.4±10.5 mm at the anterior, 14.3±7.6 mm at the middle, and 13.6±8.6 mm at the posterior aspect of the right lung base and 17.8±10.8 mm at the posterior aspect of the left lung base (Table 2). RMA could not be evaluated immediately adjoining the heart as myocardial uptake of FDG masks a large portion of the anterior aspect of the left lung.

None of the patients included in this study had an FDG-avid lesion in the region of the respiratory artifact. Thus, RMA in this study did not interfere with interpretation of CTAC PET images.

Discussion

We demonstrated that curvilinear cold artifacts (RMA) paralleling the dome of the diaphragm at the lung bases were frequently present on PET images obtained at free tidal breathing using CTAC. The RMA was mild in severity in most patients and was more noticeable in the right lung than in the left lung. RMA was not present in Ge AC images. The "cold" defect is likely due to an inaccurate correction for photon attenuation at the interface of the lung base and diaphragm owing to inconsistencies in the position of the interface between PET and CT acquisitions. The most likely source of the artifact is under-attenuation correction for the upper liver imaged at PET owing to larger lung volumes on the CT (single breath) than on the emission PET (free breathing with the expiratory phase predominant) [1, 2, 3].

Gorres has reported that the normal expiration provides excellent co-registration between PET and CT [4]. However, many cancer patients may not be able to tolerate a long breath hold. Thus, the breath-holding approach may not be practical in day-to-day clinical practice in all patients. It is probable that our tidal breathing approach may entail a smaller lung volume on PET than on CT (as expiration is longer than inspiration). This may account for inconsistencies in the AC map and the RMA that we observed.

Expiratory imaging or respiratory gating approaches should be studied to determine whether they reduce the frequency of RMA [4, 5, 6]. In the absence of careful study of those approaches, it is important to be familiar with the cold RMA. While RMA was commonly present using the free tidal breathing acquisition protocol that we find clinically practicable, RMA did not result in diagnostic challenges in the studied population. However, in a separate larger study, RMA resulted in infrequent (2%) but potentially serious localization errors [7].

Conclusion

RMA of some degree was visualized at the lung/diaphragm interface in most (84%) of our patients on CTAC PET images, likely due to differing positions of the liver and lung between CT and the subsequent PET images. Marked RMA was seen in only 10% of patients. It is important to be aware of RMA as a source of commonly seen cold artifacts at the lung/diaphragm interface in PET-CT images. RMA was not clinically problematic in the current study but warrants further study in patients with lesions located in the upper liver or lower lung fields as well as systematic approaches to minimize the artifact.

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