



Respiratory Motion Reduction in PET/CT Using Abdominal Compression for Lung Cancer Patients

Tzung-Chi Huang^{1,2*}, Yao-Ching Wang³, Yu-Rou Chiou¹, Chia-Hung Kao⁴

1 Department of Biomedical Imaging and Radiological Science, China Medical University, Taichung City, Taiwan, **2** Department of Biomedical Informatics, Asia University, Taichung City, Taiwan, **3** Department of Radiation Oncology, China Medical University Hospital, Taichung City, Taiwan, **4** Department of Nuclear Medicine, China Medical University Hospital, Taichung City, Taiwan

Abstract

Purpose: Respiratory motion causes substantial artifacts in reconstructed PET images when using helical CT as the attenuation map in PET/CT imaging. In this study, we aimed to reduce the respiratory artifacts in PET/CT images of patients with lung tumors using an abdominal compression device.

Methods: Twelve patients with lung cancer located in the middle or lower lobe of the lung were recruited. The patients were injected with 370 MBq of ¹⁸F-FDG. During PET, the patients assumed two bed positions for 1.5 min/bed. After conducting free-breathing imaging, we obtained images of the patients with abdominal compression by applying the same setup used in the free-breathing scan. The differences in the standardized uptake value (SUV)_{max}, SUV_{mean}, tumor volume, and the centroid of the tumors between PET and various CT schemes were measured.

Results: The SUV_{max} and SUV_{mean} derived from PET/CT imaging using an abdominal compression device increased for all the lesions, compared with those obtained using the conventional approach. The percentage increases were 18.1% ± 14% and 17% ± 16.8% for SUV_{max} and SUV_{mean}, respectively. PET/CT imaging combined with abdominal compression generally reduced the tumor mismatch between CT and the corresponding attenuation corrected PET images, with an average decrease of 1.9 ± 1.7 mm over all the cases.

Conclusions: PET/CT imaging combined with abdominal compression reduces respiratory artifacts and PET/CT misregistration, and enhances quantitative SUV in tumor. Abdominal compression is easy to set up and is an effective method used in PET/CT imaging for clinical oncology, especially in the thoracic region.

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* E-mail: tzungchi.huang@mail.cmu.edu.tw

Introduction

Respiratory motion causes image artifacts in PET/CT images and misalignment between PET and CT. In PET imaging, respiratory motion may give cause image blurring, degradation in the image contrast, and an overestimation of the lesion volume. In CT, respiratory motion may distort the tumor shape and volume [1]. In addition, when using CT images to correct for attenuation in PET data, the mismatch between PET and CT images caused by respiration may result in errors in localizing the tumor in PET, leading to an inaccurate standardized uptake value (SUV) because of the large difference in the acquisition time of CT and PET. An overestimation of the volume and underestimation of the SUV of a lung lesion caused by respiratory motion were reported by Nehmeh et al and Erdi et al [2–3]. Liu et al reported the increased uncertainty of the SUV for lung tumors when attenuation correction (AC) was performed using misaligned PET/CT [4]. Huang et al demonstrated that increased tumor motion is closely associated with the SUV maximum (SUV_{max})

decrease in patients with lung cancer [5]. These artifacts and the misalignment could cause potential misdiagnoses when combined with the PET/CT imaging modality for lung cancer diagnosis [6].

Several techniques have been investigated to correct the PET/CT misalignments and reduce artifacts to improve the quantitative accuracy. The respiratory gating of PET and CT, in which the collected data were binned into certain respiratory phases, was used to reduce the motion artifacts and SUV errors [7–8]. The results of applying 4-dimensional (4D) PET/CT using 4D-CT data with the gated PET images indicated improved lesion registration and appropriate internal tumor volumes [1,9]. However, the long acquisition and processing time required to conduct the examination was inevitable. The deep-inspiration breath-hold technique has been proposed to improve the inaccurate quantification of both SUV_{max} and metabolic volume, but this method is not practical for all patients because it requires patient compliance and may not be feasible for patients with limited pulmonary function [6,10]. Cine average CT (CACT) was proposed for AC in PET and the images exhibited considerably

less misalignments and artifacts compared with those obtained using conventional helical CT (HCT)-based AC [11]. The main problem of CACT is that it requires the administration of a relatively high radiation dose. Recently, the interpolated average CT used for PET/CT AC corrected the PET/CT misregistration and enhanced lesion quantitation accompanied by radiation deduction. However, the complicated postimaging process is still a concern regarding the use of these techniques in clinical practice [12–14].

Abdominal compression is commonly used for reducing thoracic tumor motion during treatment delivery in radiation oncology. The use of abdominal compression for lung radiation treatments efficiently reduces motion amplitude for lesions close to the diaphragm [15–16]. In this study, we demonstrated respiratory motion correction in PET/CT by using an abdominal compression device, and investigated the potential improvement of the results compared with those produced using conventional CT (HCT) on patients with lung cancer.

Materials and Methods

Patient Population

The current study was conducted from August 2013 to October 2013. Twelve patients (5 male, 7 female; average age, 60 years; age range, 43–77 years) with a diagnosis of lung cancer confirmed by a physician at China Medical University Hospital were recruited. The lung lesions had a size ranging from 3 to 44 cm. All the patients who were selected had a tumor in the middle or lower lobe of the lung, which are regions in which respiratory motion clearly occurs. A summary of the clinical characteristics of the patients is shown in Table 1. Written informed consent was obtained from all the patients. All the data collection and analyses performed in this study were approved by the Institutional Review Board of China Medical University Hospital.

Imaging Acquisition Protocol

The patients were all injected with 370 MBq of ^{18}F -FDG. During the uptake phase that lasted for approximately 40 minutes, the patients remained in a still position. The first whole-body image was obtained when the patients were in a supine position and the acquisition time per bed position was 1.5 min. Free-breathing whole-body CT was conducted at 120 kV in helical

mode with a smart mA (range 30–210 mA), 1.75:1 pitch, and 0.5-s gantry rotation. For the thoracic PET, the patients assumed two bed positions with 1.5 min/bed. After performing free-breathing imaging (<5 min), we obtained images of the patients with abdominal compression by using the same setup as that used in the free-breathing scan.

All the scans were acquired using a GE PET/CT-16 slice and a Discovery STE (GE Medical System, Milwaukee, Wisconsin USA) combined with an abdominal compression device (BodyFix Diaphragm Control, Elekta) in 3-dimensional mode with transaxial field-of-views (FOVs) of 70 and 50 cm for PET and CT, respectively. The imaging protocol and the patient setup including the abdominal compression device are shown in Figures 1a and 1b.

We used the same clinical reconstruction parameters for both the free-breathing PET and abdominal-compression PET images. The PET_{FB} and PET_{ab} images were reconstructed using iterative algorithms (Fourier rebinning and attenuation-weighted ordered-subset expectation maximization, two iterations, 20 subsets, and a 6-mm Gaussian filter) and AC using HCT and abdominal-compression CT (CT_{ab}), respectively. The data were reconstructed using a 128 × 128 matrix and a 3-mm-thick slice. All the PET and CT images were transferred to a GE workstation from which fusion PET/CT images were constructed.

Lesion Analysis

In the 3-dimensional (3D) PET/CT images, a 3D volume-of-interest (VOI) was manually drawn by an experienced physician for each lesion in the PET images [17]. The maximal value and the mean SUV value in the VOI were defined as SUV_{max} and SUV_{mean}, respectively. The corresponding delineation of the VOI in the CT images was performed by a radiation oncologist. SUV_{max} was obtained for all lesions shown in the PET_{FB} and PET_{ab} images. The values of the SUV_{max}, SUV_{mean}, and VOI were compared. The continuous variables were expressed as the mean ± the standard deviation (SD). Statistical analyses were conducted using the unpaired Student's *t* test and paired *t* test. A *P* value of <0.05 was considered to be statistically significant. In addition, the coordinates of the centroid of the lesion in the PET_{FB}, CT and PET_{ab}, and CT_{ab} images were determined based on the chosen VOIs. The distances *d* between the tumor centroid

Table 1. Clinical patient characteristics.

Patient no.	Sex	Age(yr)	Lesion location	Lesion volume(cm ³)
1	M	62	Right lower lobe	8.46
2	F	50	Left lower lobe	17.9
3	M	61	Left lower lobe	6.41
4	M	61	Right lower lobe	17.65
5	F	52	Right lower lobe	4.42
6	F	55	Left lower lobe	41.90
7	F	57	Right middle lobe	3.37
8	F	77	Left upper lobe	6.20
9	M	74	Right lower lobe	44.58
10	F	43	Left lower lobe	16.49
11	M	72	Right lower lobe	6.06
12	F	64	Left lower lobe	40.59

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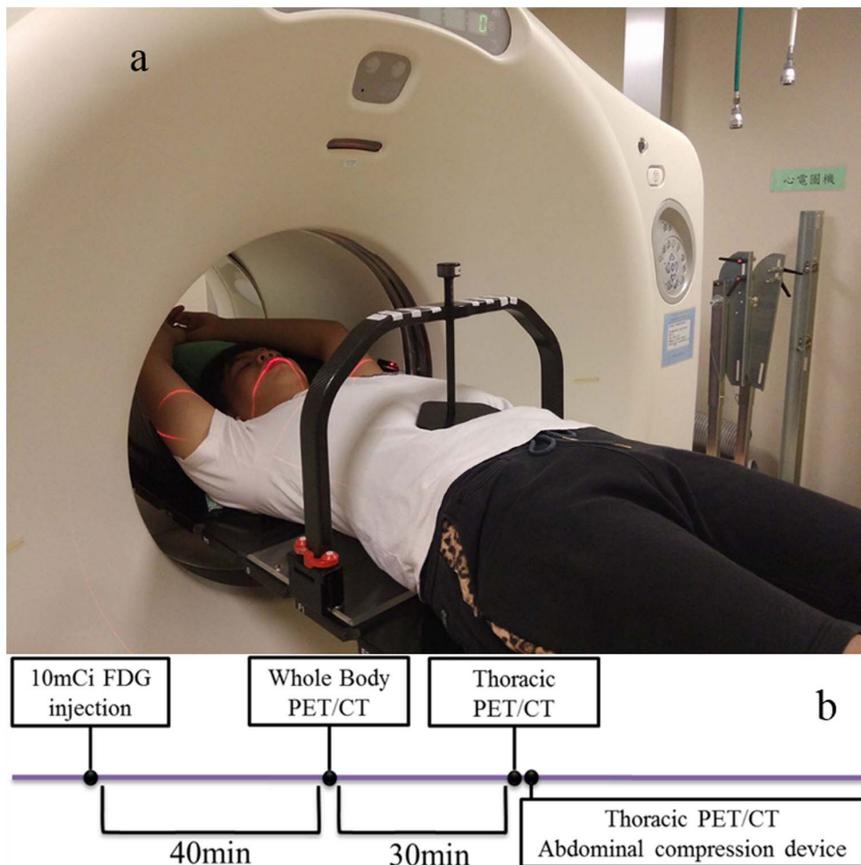


Figure 1. Patient setup with the abdominal compression device (a) located in the upper abdomen region to limit the amount of respiration. (b) The data acquisition protocol for the PET/CT imaging of patients with abdominal compression immediately after conducting free-breathing imaging. doi:10.1371/journal.pone.0098033.g001

in the PET image and the associated CT image were then measured.

Results

The SUV_{max} and SUV_{mean} for all the tumors are summarized in Table 2. The PET_{ab} image generally showed increased SUV_{max} and SUV_{mean} for all the lesions compared with those shown in the PET_{FB} image. The percentage increase (%diff) was $18.1\% \pm 14\%$ and $17\% \pm 16.8\%$ for SUV_{max} and SUV_{mean} , respectively. The percentage difference of tumor volume in PET was in the range of 0.1% to 41%. PET/CT imaging combined with abdominal compression generally reduced tumor mismatch d between the CT image and the corresponding attenuation corrected PET images, as shown in Table 2, with an average decrease of 1.9 ± 1.7 mm across all the tumors.

In Figure 2, the coronal views of the PET_{FB}/CT and PET_{ab}/CT_{ab} fusion images show the tumor in the right lower lobe for a selected patient, Patient 4, who was used as a representative example. Misalignment around the tumor (red arrow) was observed in the PET_{FB}/CT fusion images and the misalignment was substantially improved in the PET_{ab}/CT_{ab} image, as shown in Fig. 2(a) and Fig. 2(b), respectively. The values for PET_{ab} were greater than those for PET_{FB} by 8% and 13%. In addition, the vertical profiles drawn in Fig. 2(c) demonstrate that the full width at half maximum was smaller for the tumor shown in the PET_{ab} image, indicating less blurring around the edges of the tumor in

the image, and a greater SUV_{max} was also easily observed in the PET_{ab} image, thereby enabling more accurate and precise tumor detection.

Discussion

An abdominal compression device can be used to reduce lung tumor motion [18]. The efficiency of abdominal compression for reducing lung tumor motion depends on the tumor location within the lung. The significant effects of abdominal compression was assessed by Bouilhol et al [16]. The present study further demonstrated that PET/CT imaging incorporating abdominal compression potentially improved reconstructed PET image quality and produces increased SUVs of the tumors and reduced the respiratory artifacts containing spatial match in the PET and CT fusion images. Several concerns that may arise are that the increased SUV in the abdominal-compression images was caused by abdominal compression, or that in reality, the SUV will increase in active tumors with time postinjection because abdominal-compression PET acquisition was performed after conducting free-breathing PET acquisition on all of the patients. However, the results of this study revealed that the mean PD of SUV_{max} was 18%, which is too high to achieve time postinjection on the tumor within less than 5 minutes. In addition, the additional preparation time required to set up the abdominal compression device was typically less than 5 minutes in our clinical practice. Therefore, using the abdominal compression device for

Table 2. Summary of the quantitative results obtained using the conventional and abdominal compression methods.

Patient #	SUV _{max}		SUV _{mean}		Tumor Volume (cm ³)				d (mm)		
	PET _{HCT}	PET _{ab}	%diff	PET _{HCT}	PET _{ab}	PET _{HCT}	PET _{ab}	%diff	HCT/PET _{HCT}	CT _{ab} /PET ^{ab}	Diff. (mm)
1	3.3	3.9	18	1.8	2.3	8.5	5.6	34	5.7	3.7	2.0
2	12.8	14.5	13	7.7	8.7	17.9	16.9	6	5.2	4.2	1.0
3	6.0	6.6	10	3.6	3.7	6.415	3.8	41	5.2	3.6	1.6
4	6.3	6.7	6	3.4	3.9	17.7	12.9	27	7.0	6.0	1
5	3.5	4.6	31	2.0	2.3	4.4	2.6	41	3.7	3.4	0.3
6	11.2	12.0	7	6.6	6.8	41.9	37.4	11	4.9	3.7	1.2
7	6.0	8.0	33	3.5	4.2	3.4	2.5	26	3.4	3.2	0.2
8	7.00	7.9	13	4.4	4.7	6.2	6.2	0.1	5.5	2.7	2.8
9	10.3	11.6	13	5.4	6.2	44.6	35.2	21	11.5	5.4	6.1
10	4.8	5.5	15	2.7	3.2	16.5	10.6	36	8.4	4.0	4.4
11	3.9	6.0	54	2.0	3.3	6.1	4.0	34	4.4	3.9	0.5
12	7.6	7.9	39	4.6	4.8	40.6	40.1	1	3.6	2.1	1.5
p-value			p=0.0001					P=0.0003			P=0.0002

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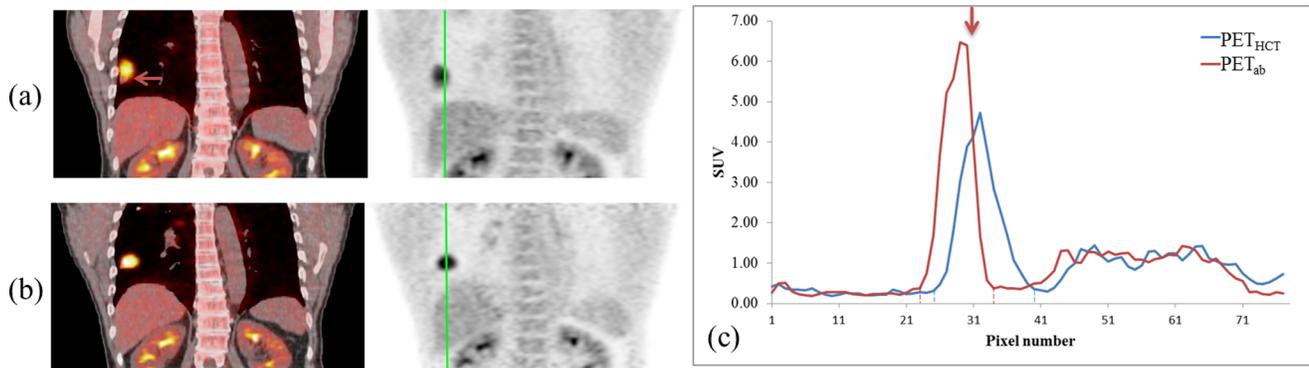


Figure 2. Coronal images of the (a) PET_{FB}/CT fusion image (left); PET_{FB} (right) and (b) PET_{ab}/CT_{ab} fusion image (left); and PET_{ab} (right) image for the selected patient, Patient 4. Misalignment around the tumor was observed in the PET_{FB}/CT fusion images (red arrow). (c) Vertical image profiles are drawn across the tumor in the PET_{FB} and PET_{ab} images.
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thoracic PET/CT acquisition is feasible for routine clinical use. There are two concerns regarding the use of abdominal compression: First, imaging combined with abdominal compression may cause discomfort and possible anxiety for some patients and is also unusable for obese patients. Second, abdominal compression might be a potential source of increased tumor motion variability, leading to inconsistencies in tumor delineation during simulation CT for radiation treatment planning [19]. To solve this problem, concatenating the deformable image registration to the abdominal compression is a possible option for linking simulation CT and CT_{ab} for delineating tumors [20].

Several studies have reported that a decrease in SUV in 3D PET scans is caused by the amount of displacement that occurs and the pattern of respiration motion. The 4D PET scan can be used to reduce the decrease in SUV induced by respiratory motion [6,21–22]. This study demonstrated that PET imaging combined with abdominal compression device can also improve the SUV. Increases in both the SUV_{max} and SUV_{mean} for PET_{ab} compared with those for PET_{FB} were observed in this study. Tumors closer to the diaphragm clearly moved with a large amplitude in the superior-inferior direction; therefore, large SUV_{max} differences

between 4D PET and 3D PET scans exist and have been reported in numerous studies. In this study, patient with tumors located in the middle to lower lobes of the lung were recruited and the SUV_{max} was successfully improved by approximately 7%–54%.

The movement of the structures in the thorax is highly correlated to the diaphragm motion that occurs during respiration [23]. This movement typically causes a larger tumor volume size to appear in PET images, compared with the actual size of the tumor, leading to PET/CT misalignment [14]. The motion is even more complex when the lesions are attached to the rigid structure of the thorax, (eg, the pleura near the ribcage (Patients 3 and 10) and the diaphragm (Patient 5)). In this study, we observed significant differences in the quantification results, which indicated that the lesions attached to the rigid structure of the thorax demonstrated large volume changes (Fig. 3) between the images obtained with and without the use of abdominal compression. However, the effects of using abdominal compression on the lesion size, location, uptake ratio, and movement pattern are being further investigated in our current study.

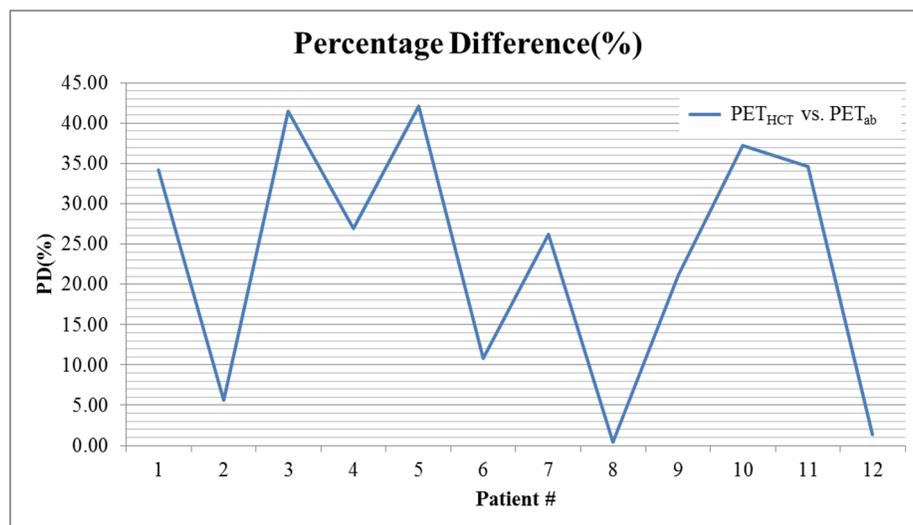


Figure 3. Percentage difference (PD %) in tumor volume derived from PET images of the patients.
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Conclusion

We provided the preliminary results regarding the differences in tumor motion caused by respiration in 12 lung cancer patients imaged using an abdominal compression device, compared with the images obtained using the conventional approach. The results demonstrated that the reduction in overall PET image quality resulted from respiratory motion and the mismatch between PET

and CT caused by using CT for AC in PET to incorporate the abdominal compression device in PET/CT imaging.

Author Contributions

Conceived and designed the experiments: TH YW. Performed the experiments: TH YC. Analyzed the data: TH YW YC. Contributed reagents/materials/analysis tools: CK. Wrote the paper: TH.

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