Original Investigation

Detecting Pulmonary Nodules in Lung Cancer Patients Using Whole Body FDG PET/CT, High-resolution Lung Reformat of FDG PET/CT, or Diagnostic Breath Hold Chest CT

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Rationale and Objectives: Pulmonary nodules can be missed on the non-breath hold computed tomography (CT) portion of 18F-fluorodeoxyglucose positron emission tomography/computed tomography (FDG PET/CT), and for this reason prior studies have advocated for routinely performing dedicated breath hold CT of the chest in addition to PET/CT for routine staging of malignancy. We evaluated the rate of pulmonary nodule detection on standard CT images from whole body PET/CT studies (WB-PET/CT), high-resolution lung reconstruction CT images from PET/CT studies (HR-PET/CT), and diagnostic breath hold chest CT (BH-CT).

Materials and Methods: A cohort of 25 patients was identified who had a history of lung cancer as well as a PET/CT staging or re-staging scan and BH-CT within 30 days of each other. All PET/CTs included a set of CT images using a soft tissue algorithm filter and 3.75- to 5-mm slice thickness, as well as high-resolution reformats with a sharp reconstruction filter and 2-mm slice thickness. The CT images from WB-PET/CT, HR-PET/CT, and BH-CT were reviewed by three radiologists. Significance was analyzed by two-way repeated measures analysis of variance.

Results: There were 2.84 nodules found per patient with WB-PET/CT, 3.85 nodules with HR-PET/CT, and 3.91 nodules with BH-CT. When only nodules less than or equal to 8 mm in size were considered, WB-PET/CT also demonstrated significantly fewer nodules (1.98) compared to the HR-PET/CT (2.94) or a BH-CT (2.86) ($P < 0.001$). No difference in detection rate was noted between the two higher resolution modalities.

Conclusions: More pulmonary nodules are detected on the CT portion of PET/CT studies when high-resolution reformatted images are created and reviewed. The ability to detect nodules with the reformatted images was indistinguishable from dedicated BH-CT. Overall, high-resolution reformats of PET/CT images of the lungs can increase the sensitivity for pulmonary nodule detection, approaching that of dedicated BH-CT. These data suggest that if HR-PET/CT reformats are used, additional dedicated BH-CT is unnecessary for routine staging of lung cancer.

Key Words: PET/CT; pulmonary nodule; high-resolution reconstruction; breath hold; non-small cell lung cancer.

INTRODUCTION

18F-Fluorodeoxyglucose (FDG) positron emission tomography combined with whole body computed tomography (PET/CT) has become the standard of care imaging test for staging of patients with non-small cell lung cancer (NSCLC) (1). Staging of NSCLC is performed using the tumor, node, metastasis (TNM) classification system (2–5). Multiple prior studies have demonstrated that PET/CT is superior to CT alone for staging the primary mass (T stage) (6), associated nodal disease (N stage) (7), and distant metastasis (M stage) (8). For these reasons, PET/CT has become widely used for this application.

The presence or absence of pulmonary nodules, distinct from the primary mass, is an important contributor to the overall stage of NSCLC (3–5). Specifically, the presence of other nodules in the same lobe as the primary tumor confers the T3 stage, and the presence of nodules in the same side, different lobe, results in a T4 tumor. Metastatic pulmonary nodules

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in the contralateral lung confer M1a disease. An accurate assessment for nodules suggestive of metastatic disease can only be accomplished via imaging; therefore, it is critical to accurately assess the presence of even small pulmonary nodules.

Several investigators have previously investigated the ability of PET/CT to detect pulmonary nodules, and compared against conventional breath hold chest CT (BH-CT) (9–12). Overall, these studies have found that small pulmonary nodules can be missed on PET/CT in comparison with conventional CT, because of the non-breath-hold technique on PET/CT, as well as the low spatial resolution of the CT component of the examination (including generally thick slices and lower in-plane resolution with large fields of view). Furthermore, small pulmonary nodules below 1 cm in size are often not seen on the PET portion of the examination (13,14). This has led some authors to conclude that PET/CT is insufficient to completely stage malignancies because of the missed nodules (10–12). In most routine PET/CT scans, the images are reconstructed using a relatively thick slices (typically 5 mm), with soft tissue reconstruction algorithm. Prior studies have demonstrated that using thinner slices (1.25 mm) can improve the rate of pulmonary nodule detection on routine BH-CT (15). At our institution, we commonly reformat CT images from PET/CT studies with a high-resolution reconstruction to improve the detection of pulmonary nodules, although the added value from these reformations is unknown.

The objective of this study was to assess the ability to detect pulmonary nodules on high-resolution reformatted CT images compared to standard CT images obtained as part of whole body PET-CT (WB-PET/CT) studies. Although it is likely that improved resolution should yield some improvement in nodule detection, this has not been previously investigated in the PET/CT context. We compared the ability to detect nodules on both sets of images to that of diagnostic BH-CTs. We hypothesized that the high-resolution reformats would reveal more nodules than the standard CT images from WB-PET/CT, and that the increased sensitivity would be similar to those obtained via dedicated chest CT studies.

METHODS

Patient Selection

This retrospective study was approved by our institution's institutional review board (IRB) and informed consent was waived. We searched our database of all PET/CT performed between February 2012 and July 2013 at our institution for the presence of the term "lung cancer." Scans of patients who met the following inclusion criteria were included up to our target enrollment of 25 patients:

1. Biopsy-proven diagnosis of NSCLC at the time of the imaging studies
2. No definitive evidence of distant metastatic disease (thereby restricting the cohort to patients for whom an accurate identification of pulmonary nodules could matter to the stage)
3. PET/CT and BH-CT imaging studies obtained at our institution within 30 days of each other were available in picture archiving and communications system (PACS)

Scan Technique

FDG PET/CT examinations were performed on either a Biograph 16 (Hi-Rez) PET/CT scanner (Siemens AG, Erlangen, Germany) with an integrated PET and 16-MDCT scanner, or a Discovery VCT PET/CT scanner (GE Medical Systems, Milwaukee, WI) with an integrated PET and 64-MDCT scanner. All patients fasted with hydration for at least 6 hours. Patients had blood glucose levels <200 mg/dL. Of 18F-FDG, 0.45 ± 0.09 GBq (12.2 ± 2.4 mCi) was injected intravenously, followed by a 10-mL normal saline flush. Patients rested for 60 ± 15 minutes and voided before being positioned supine on the scanner table. The CT portion of the PET/CT was performed in neutral breath hold after the injection of 150 mL of iohexol (Omnipaque 350; GE Healthcare, Wauwatosa, Wisconsin, USA) at 3 mL/s. Acquisition was performed at a kVp of 120 with auto-mAs. Whole body CT images were reconstructed as contiguous 3.75- or 5-mm slices. Lung reformation CT images were generated using 2-mm slice thickness and a sharp reconstruction algorithm. PET was performed immediately following CT, without patient repositioning. PET images were obtained in 3D mode at 7–10 bed positions per patient, with an acquisition time of 3–4 minutes per station, from the skull vertex through the mid-thigh.

BH-CT examinations were performed on 16- or 64-slice General Electric Lightspeed VCT scanners, at a kVp of 120 with auto-mAs. Images were reconstructed as contiguous 1.25-mm transaxial slices using standard chest CT reconstruction algorithms that were optimized for both lung and soft tissue evaluation (the degree of edge enhancement was in between that used for abdominal CTs and those used for high resolution computed tomography (HRCT)s to evaluate for interstitial lung disease). A portion of the BH-CT was performed with contrast: 70–150 mL of Omnipaque 350.

Imaging and Chart Review

The medical charts of patients included in the study were reviewed for demographic data and histologic confirmation of diagnosis. All cases were reviewed independently for the presence of pulmonary nodules by three radiologists with 4, 9, and 9 years of CT experience. One reader was a radiology resident with 3 years experience, one was an abdominal imaging and nuclear medicine with 9 years of CT experience, and fellowship training in abdominal imaging and nuclear medicine, and one was a thoracic radiology and nuclear medicine with 9 years of CT experience, and fellowship training in thoracic radiology and nuclear medicine. Each reader reviewed the three sets of images of all 25 patients, thereby resulting in 75 reviewed studies. The order the studies were reviewed was randomized and divided into three separate blocks of 25 examinations. Each set of 25 examinations was reviewed