Minimizing Image Misregistration during PET/CT–guided Percutaneous Interventions with Monitored Breath-hold PET and CT Acquisitions

Paul B. Shyn, MD, Servet Tatli, MD, Nisha I. Sainani, MD, Paul R. Morrison, MSc, Fadi Habbab, MD, Paul Catalano, ScD, and Stuart G. Silverman, MD

ABSTRACT

Purpose: To validate a monitored, breath-hold positron emission tomography (PET)/computed tomography (CT) acquisition technique for the minimization of respiratory PET/CT image misregistration and lesion distortion during PET/CT–guided percutaneous interventional procedures.

Materials and Methods: Eleven patients referred for percutaneous biopsy or thermal ablation of tumors near the diaphragm were prospectively enrolled. Initial PET/CT scanning was performed by using a bellows device and monitored, same-level breath-holds for PET and CT acquisitions. Breath-hold PET consisted of nine 20-second breath-hold frames, yielding a 3-minute equivalent PET dataset. A second PET/CT scan was obtained without monitoring by using end-expiration breath-hold CT and free-breathing PET. PET/CT tumor misregistration and craniocaudal tumor diameter were measured on monitored and unmonitored PET/CT datasets. Data were analyzed by using nonparametric, two-sided, signed-rank statistical tests.

Results: Mean PET/CT image misregistrations in the craniocaudal, anteroposterior, and transverse planes were 2.6 mm (range, 0–7 mm), 3.3 mm (range, 1–8 mm), and 2.7 mm (range, 0–8 mm) with monitoring and 14.7 mm (range, 0–49 mm), 7.6 mm (range, 1–24 mm), and 4.0 mm (range, 0–12 mm) without monitoring, respectively. Differences were significant for craniocaudal ($P = .0087$) and anteroposterior ($P = .014$) planes, but not for the transverse plane ($P = .23$). Mean craniocaudal target diameter was 2.5 mm (range, −2 to 9 mm) larger (ie, distorted) for unmonitored versus monitored PET ($P = .061$).

Conclusions: Acquiring PET/CT datasets with respiratory bellows-assisted, monitored breath-holds improves PET/CT image registration versus unmonitored PET/CT and may facilitate accurate targeting during PET/CT–guided interventions in anatomic regions subject to respiratory motion.

ABBREVIATIONS

^{18}F = fluorine-18, FDG = fluorodeoxyglucose, PET = positron emission tomography

Positron emission tomography (PET)/computed tomography (CT) as a guidance modality for interventional radiology procedures is beginning to be investigated and offers the advantage of targeting metabolically active lesions visible on PET but not visible or poorly visible on CT (1–3). PET and CT image misregistration resulting from respiratory motion during PET/CT–guided percutaneous interventions poses a targeting problem, particularly for structures near the diaphragm, that has received little attention in the literature (3,4). PET/CT misregistration is a recognized problem for diagnostic and radiation therapy planning applications (5–7). PET/CT misregistration results in anatomic misalignment of the PET and CT datasets and is of particular concern, from an interventional point of view,

From the Division of Abdominal Imaging and Intervention, Department of Radiology (P.B.S., S.T., N.I.S., P.R.M., F.H., S.G.S.), Brigham and Women's Hospital and Harvard Medical School; and Department of Biostatistics and Computational Biology (P.C.), Dana–Farber Cancer Institute, Boston, Massachusetts. Received April 28, 2011; final revision received June 19, 2011; accepted June 22, 2011. **Address correspondence to** P.B.S., Division of Abdominal Imaging and Intervention, Department of Radiology, Brigham and Women's Hospital, 75 Francis Street, Boston, MA 02115; E-mail: pshyn@partners.org

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when target lesions are small or not well visualized on CT. Respiratory motion during PET acquisitions can also create apparent distortions of lesion size along lines of respiratory motion (8). Diagnostic PET/CT scans are often obtained by using unmonitored, quiet free-breathing PET acquisitions and end-expiration, breath-hold CT acquisitions, an approach known to minimize, but not eliminate, respiratory misregistration (9). Whereas the CT component of a PET/CT scan can easily be obtained during a single breath-hold, the PET component of a PET/CT scan is obtained during free breathing as a result of a mandatory acquisition time of approximately 1–5 minutes per bed position. Subdividing the PET acquisition into multiple deep-inspiration, breath-hold frames and then summing the data into one image dataset has recently been described for diagnostic thoracic PET/CT (10,11). This technique could be combined with a respiratory bellows feedback device to produce same-level, breath-hold PET and CT images that result in more optimally registered PET/CT images for interventional purposes. The purpose of this study was to validate a monitored, breath-hold PET/CT acquisition technique to minimize respiratory PET/CT image misregistration and lesion distortion during PET/CT–guided percutaneous interventional procedures.

MATERIALS AND METHODS

Patients and Interventional Procedures

This study was conducted with institutional review board approval and in compliance with the Health Insurance Portability and Accountability Act. Informed consent was obtained from each enrolled patient. Sixteen patients were initially referred for percutaneous biopsy or thermal ablation of malignant tumors located in organs near the diaphragm. Target tumor visibility on fluorine-18 (^{18}F)–fluorodeoxyglucose (FDG) PET and unenhanced CT was required to facilitate quantitative measurements of PET/CT misregistration and target size. Three patients were excluded for lack of tumor ^{18}F-FDG avidity and two were excluded because the respiratory bellows device could not track respiratory motion as a result of obesity. Eleven patients (four men, seven women; age range, 38–78 y) were prospectively enrolled from November 2008 through December 2009. The primary malignancies included lung (n = 2), colorectal (n = 3), esophageal (n = 2), and breast carcinomas (n = 2), as well as lung sarcoma (n = 1) and poorly differentiated carcinoma of unknown primary tumor (n = 1).

Fluorine-18–FDG PET/CT–guided procedures included six liver biopsies, four liver ablations (one radiofrequency ablation and three cryoablation procedures), and one right lower-lobe lung cryoablation. Of the 10 liver lesions, two were located in segment VI, two in segment IVB, two in segment III, and one each in segments II, V, VII, and VIII. Tumors ranged in size from 13 to 30 mm (mean, 23.5 mm). Moderate intravenous sedation was administered after the initial PET/CT scan in all cases. Two attending radiologists with extensive experience in image-guided thermal ablation procedures and biopsies performed all procedures. Tumors were biopsied by placing a single 20-gauge Chiba needle (Cook, Bloomington, Indiana) into the lesion, followed by multiple coaxial 25-gauge Chiba needle aspiration biopsies. One tumor was ablated by using three individual internally cooled electrodes operated sequentially by a radiofrequency generator/switching controller (Cool-tip RF ablation system; Covidien, Boulder, Colorado). Four tumors were cryoablated by using simultaneous activation of three to five cryoablation applicators connected to an argon-based cryoablation system (CryoHit; Galil Medical, Minneapolis, Minnesota). Contrast-enhanced magnetic resonance (MR) imaging or CT, performed at least 1 day after the ablation procedure, confirmed technical success of all ablation procedures based on complete coverage of the tumor by the hypoenhancing ablation zone. All biopsies were diagnostic for malignancy based on final cytopathology reports. No procedural complications were encountered.

PET/CT Scanning and Analysis

A Discovery VCT 64 PET/CT scanner (GE Medical Systems, Milwaukee, Wisconsin) was used for all PET/CT interventional procedures. Blood glucose levels measured immediately before injection of ^{18}F-FDG ranged from 74 to 153 mg/dL (mean, 108 mg/dL). A single intravenous dose of ^{18}F-FDG, 385–622 MBq (mean, 518 MBq), was administered 68–93 minutes (mean, 81 min) before the initial PET/CT scan. All PET/CT scans were limited to a single bed position.

A respiratory bellows device, the Interactive Breath-hold Control System (Medspira, Minneapolis, Minnesota), was used to achieve reproducible degrees of breath holding, and has been previously described (12). The bellows was positioned around the patient's torso at the point of maximum respiratory excursion, but not to interfere with interventional access (**Fig 1**). Three feedback monitors were positioned so that the interventional radiologist, PET/CT technologist, and patient could see the monitors throughout the procedure. The radiologist coached the patient on using the monitor to insure identical or same-level breath-holds for PET and CT acquisitions. The initial PET/CT scan was performed by using monitored, same-level breath-holds for both the CT and PET acquisitions. PET acquisitions used nine 20-second breath-hold frames, at a predetermined level of expiration, that were summed for a 3-minute equivalent PET dataset. Each 20-second frame was preceded by two or three slow, deep breaths over 40 seconds. The monitored breath-hold PET dataset was completed in 9 minutes. The same expiratory breath-hold was used for the CT acquisition. This initial PET/CT scan served for planning the procedural approach and for choosing a skin entry location for marking.

The second PET/CT scan, obtained after sedation and without respiratory monitoring, incorporated an end-tidal, expiration breath-hold CT acquisition and a free-breathing